Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 1026 Steel

Getenet Worku Daba

A Thesis Submitted to Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 1026 Steel" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Getenet Worku Daba	______________________	_______________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 1026 Steel" prepared under my guidance by **Getenet Worku Daba** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Guteta Kabeta	____________________	_______________
Advisor	Signature	Date

APPROVAL SHEET

I, the advisor of the thesis entitled "Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 1026 Steel" and developed by **Getenet Worku Daba**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Guteta Kabeta	______________________	________________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Getenet Worku Daba** have read and evaluated the thesis entitled "Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 1026 Steel" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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ACRONYMS AND ABBREVIATIONS

AISI	American Iron and Steel Institute
ANOVA	Analysis of Variance
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CBN	Cubic Boron Nitride
CNC	Computer Numerical Control
DOE	Design of Experiment
DOF	Degree of Freedom
GA	Genetic Algorithm
GRA	Gray relational analysis
HSS	High Speed Steel
ISO	International Standard Organization
MQL	Minimum Quantity Lubrication
MRR	Material Removal Rate
MSS	Mean Sum of Square
OA	Orthogonal Array
Ra	Surface roughness
rpm	Revolution per minute
RSM	Response Surface Methodology
SNR	Signal to Noise Ratio
SST	Total Sum of Squares

ABSTRACT

Increasing quality and productivity of machined parts are the main challenges of machining operations in metal working industries. Turning is one of the most widely used machining operations to remove material and produce reasonably good surface finish quality, which is influenced by different factors like cutting speed, feed rate, tool geometry, cutting tool and cutting fluid. Dry turning is applicable for conventional machining on steels, steel alloys and cast irons and it has advantages in respect to environmental aspects, minimizing cost of fluid to be used and for safety of operators. Optimizing of cutting parameters plays a vital role in improving surface finish that minimizes mechanical failures caused by wear, corrosion, and increasing productivity of the products. This research focused on experimentally studying and optimizing cutting parameters (spindle speed, depth of cut, and feed rate) on surface roughness, material removal rate, tool tip temperature, machining time and tool wear rate in dry turning of AISI 1026 steel using carbide cutting tools. Taguchi L9 orthogonal array was selected for the design of the experiment and analysis of variance was used to determine the effect of cutting parameters on end responses. The result revealed that spindle speed has the highest contribution (63.78%) followed by feed rate (27.78%) in affecting surface roughness. Minimum surface roughness (1.063 µm) was attained at 1100 rpm spindle speed, 0.2 mm depth of cut and 0.05 mm/rev feed rate and maximum surface roughness (2.787 µm) was attained at 500 rpm spindle speed, 1 mm depth of cut and 0.15 mm/rev feed rate. Material removal rate was significantly affected by depth of cut followed by feed rate and spindle speed, and its value at optimal surface roughness was 4148.63 mm^3/min. Machining time is significantly affected by feed rate (with a contribution of 64.82%), followed by spindle speed (29.62%) and depth of cut (2.50%). Minimum tool wear rate (0.855 mm^3/min) was attained at 500 rpm spindle speed, 0.2 mm depth of cut and 0.05 mm/rev feed rate. An increase in spindle speed results in an increase in tool tip temperature, which has a direct influence on tool wear rate.

Key words: AISI 1026 steel, Optimization, Dry turning, Surface roughness

CHAPTER -1

INTRODUCTION

1.1. Background of the study

Steel is an alloy made up of iron with a small percentage of carbon to improve its fracture resistance and strength compared to other forms of iron. Carbon steel is a steel with a carbon content of about 0.05 up to 2.1% by weight. Depending on the amount of carbon content, steels can be classified as low carbon steels (0.05–0.30%), medium carbon steels (0.3–0.5%) and high carbon steels (more than 0.6%).

Low carbon steels are the most common type of steel used in manufacturing industries due to its availability, higher machinability, and lower cost. Low carbon steels provide material properties that are suitable for many applications, other than iron (Butola *et al.*, 2017). They are mainly used as an all-purpose engineering material and have 0.05–0.30% carbon content, which makes them ductile, malleable and have good tensile strength. AISI 1026 is one category of low carbon steel that has a carbon content of 0.22-0.28%, and it is used as structural steel in construction, bridges, rail-way stations, industrial equipment, shipping containers, commercial appliances, decorative items, chains, rivets, bolts, keys, shafts, food cans, car parts, piping, garden hooks and automobile exhausts. Proper machining of the surface combining optimum cutting parameters that give a lower value of surface roughness results in minimizing corrosion that occurs on the surface of material, wear, crack formation and propagation.

Machining is a process in which raw materials of different sizes and shapes are converted to required dimensions by removing undesirable material from the work-piece using cutting tools. Machining plays a significant role in the manufacturing industries since most of the products are depend on machining operation. Manufacturing industries are focused not just on increasing productivity but also on improving the quality of the product. The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, reaming, broaching, sawing, etc. Lathe is the most common method used in industries widely.

Lathe machine is one of the oldest machine tools, and it is used to do different useful operations like turning, grooving, treading, knurling, tapering, boring and chamfering.

Turning is the most commonly used operation due to its advantages of high speed to remove material and produce reasonably good surface quality (Sahoo, 2011). Turning is a process of machining a work piece to the required size and shape by removing surplus metal from the work piece owing to the relative motion of a single point cutting tool either parallel or perpendicular to the rotating cylindrical work piece. The most important thing in turning operation is to select the optimum cutting parameters to bring about good surface quality, high material removal rate, and minimum tool wear rate. The effect of cutting parameters is reflected in the surface quality, size and texture of the work piece. Ranges of the specified cutting parameters are usually determined by supporting experience or by using the handbook (Quintana and Ciurana, 2011).

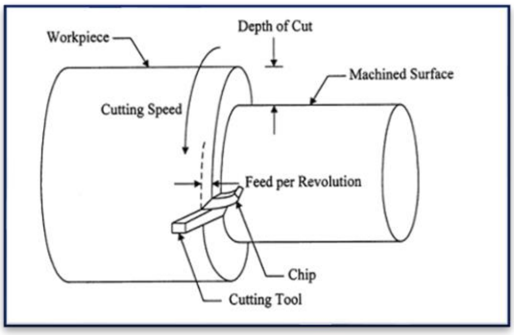

Figure 1.1. Schematic of basic turning operation (Angwenyi *et al*., 2021)

To determine the optimal cutting parameters, different kinds of optimization techniques can be used and Taguchi optimization technique is widely used since it minimizes the number of experiments required that result in a shorter period of time and minimizes the cost required to conduct the experiment.

1.2. Surface roughness

Surface roughness is a principal characteristic in valuing the surface quality of the machined component which is included in the machining drawing (Dolaimy, 2016). In turning operations, surface quality plays a major role in the mechanical behavior of the work-piece machined such as fatigue resistance, corrosion resistant, and creep strength (Panneerselvam *et al.*,2021). Surface roughness, often shortened to roughness, is a component of surface texture. It is measured by deviation in the direction of the normal vector of the real surface from its ideal form. We can say the surface is rough if these deviations are large; if they are small, the surface is smooth. The surface roughness value of any machining process decides the quality of the end product (Radha Krishnan *et al.*, 2019).

According to ASME (1985), surface finish is defined as the geometrical irregularities of a solid surface and surface roughness is defined as the greater extent of irregularities of surface texture that result from inherent action of the assembly process, like feed marks produced during machining. Roughness is the best point parameter of the performance of a material or component since irregularities in the surface of the material will form a nucleation site for corrosion and cracks. Rough surfaces usually wear more quickly and have a higher frictional coefficient than smooth surfaces. In the actual application, the surface roughness of the material being machined plays an important role in such things as light reflection, heat transmission, wear, friction due to physical contact, load carrying capacity, coating or resisting fatigue, ability to distribute and hold lubricant (Panneerselvam *et al*., 2021). Surface finish in turning operation is found to be influenced by different factors, such as depth of cut, cutting speed, feed rate, material characteristics, tool geometry, stability of machine tool, type of cutting tool, cutting fluid and workpiece deflection. The three primary input control parameters in turning operations that affect the surface finish are cutting speed, feed rate and depth of cut; where cutting speed is the relative velocity between the surface of the workpiece and cutting tool, depth of cut is the thickness of the material that can be removed by one pass of the cutting tool over the workpiece and feed rate is the relative velocity at which the cutter is advanced along the workpiece in which its vector is perpendicular to the vector of cutting speed. In machining operation, the challenge is to get the surface roughness that is achievable on conventional processes without carrying out any post finishing processes. Surface roughness can be measured using the surface roughness measurement tool known as profilometer.

It is expensive and not easy to control the surface roughness of a material, but it is possible to minimize it by selecting the optimum cutting parameters, cutting tool and machining conditions. There are three kinds of cutting environment, namely wet, minimum quantity lubricant (MQL) and dry. In the machining of a work-piece in a wet or flooded condition, the surface roughness is improved and becomes smoother than if it is machined in a dry condition (Butola *et al*., 2017). The application of cutting coolant increases tool life as well as the surface topography of the workpiece. Besides its advantages, the use of cutting fluid in a machining process has demerits like environmental impact and the high cost of the cutting fluid. Approximately, 85% of lubricants being used around the world are petroleum-based oil and enormous use of this oil has had demerits on environmental and health diseases (Shokoohi *et al.,* 2015). It is reported that around 80 % of all occupational infections of machinists are due to skin contact with cutting fluids (Shashidhara and Jayaram, 2010). Compared to petroleum-based oils, MQL is an environmentally friendly cutting fluid, but is not able to eliminate the health problems entirely due to the existence of oil mist in the machining surroundings (Pota, 2019). The cutting effect in the MQL machining is improved than in the flooded condition (Joshi *et al.*, 2018). Dry machining is applicable for conventional machining on steels, steel alloys and cast irons except for aluminum alloys (Debnath *et al*., 2015). In dry machining, the required surface quality and cutting tool life cannot be achieved due to high heat generation at the cutting zone, which affects the hardness and sharpness of the cutting tool (Rajasekaran *et al.*, 2013), but if proper cutting tools are selected and the optimal cutting parameters are applied during the dry machining process, the surface roughness of the work-piece will be improved within the minimum tool wear rate and the advantages of reducing the environmental hazard of cutting fluids and minimizing the cost of production.

Table 1.1. Factors Influencing Cutting Process (Nair *et al*.,2018)

Parameters	Influence
Cutting speed, depth of cut, feed, and cutting fluids	Temperature rise, tool life, type of chips, power consumption, surface finish.
Tool angles	All the above, Influence on chip flow direction, resistance to tool chipping
Continuous chip	Good surface finish, steady cutting force, undesirable in automated machinery
Built up edge	Poor surface finish
Discontinuous chip	Desirable for ease of chip disposal, fluctuating cutting force can affect surface finish and cause vibration and chatter
Temperature rise	Influence surface finish, dimensional accuracy, force and power
Tool wear	Influence surface finish, dimensional accuracy, temperature rise, force and power
Machinability	Related to tool life, surface finish, force and power

1.3. Tool wear

Cutting tools are exposed to a tremendously severe rubbing process. They are in metal-to-metal interaction between the chip and work-piece, under high temperature and stress. Tool wear is the continuing failure of cutting tools due to steady tasks or it can be defined as the change of shape of the tool from its original shape during cutting resulting from the gradual loss of the cutting tool. Tool wear depends on type of tool and workpiece material, tool shape, cutting conditions and cutting parameters. Tool wear results in; increasing cutting temperature and cutting force, decreasing the accuracy of produced parts, poor surface finish and decreasing tool life. The variety of wear patterns observed at the flank and rake faces are called gradual wear. Tool wear can be measured by subtracting the size of the unworn size after machining from the size of the clearance face before machining.

This research aims to experimentally study the effect of cutting parameters (spindle speed, depth of cut and feed rate) on the surface roughness, tool tip temperature, tool wear rate and material removal rate (MRR) of AISI 1026 steel in dry turning conditions. In this present work, Taguchi technique is used to analyses and predict the end responses.

1.4. Research motivation

During the internship of one month in Muger Cement Factory, it is found that as low carbon steel has a wide application in industry. Especially, the factory used AISI 1026 steel to make shafts, keys, key-ways, bolts, nuts, and different machine parts. In machining of these steels, attaining the required surface roughness and removing surplus from the workpiece within required period of time was the main challenge in the factory. If the end products have lower surface quality, the product will corrode faster, cracks will be formed, life of the product will shorten and it will require additional time and cost to replace the products (Goyal *et al*.,2016). The motivation for this work is mainly to simplify the challenges mentioned above by conducting an experiment and selecting optimal cutting parameters that results in better end responses.

1.5. Statement of the problem

In most applications, surface roughness should be kept as low as possible to avoid the occurrence of defects such as dimensional inaccuracy, wear, corrosion, valley formation and crack formation. Surface roughness reduces the surface quality of the material and results in the high cost to make it better. Since varieties of materials to be worked, it's challenging for machining industries to produce a product with a higher surface finish at specified time, and minimum tool wear rate for each type of material being machined. Selecting suitable cutting tool material and optimizing cutting parameters (spindle speed, depth of cut, and feed rate) will lead to getting a minimum surface roughness within a specified time and a minimum tool wear rate.

1.6. Objective of the study

1.6.1. General objective

The general objective of this research is to experimentally study and to optimize cutting parameters during dry turning of AISI 1026 steel.

1.6.2. Specific objectives

The specific objectives are

a) Investigating the effect of cutting parameters on surface roughness.
b) Studying material removal rate at optimized cutting conditions.
c) Studying the effect of cutting parameters on machining time.
d) Examining the influence of tool tip temperature on tool wear rate.

1.7. Significance of the study

Developing an optimal combination of machining parameters through experiments on surface roughness, material removal rate, machining time and tool wear rate has high significance in producing a high-quality product within the required period of time and minimum cost, which leads to significant profit for manufacturing industries.

1.8. Scope and Limitation of the study

The scope of this research work was dry turning of AISI 1026 steel on a conventional lathe machine using a carbide cutting tool and studying the effect of machining parameters, such as (spindle speed, depth of cut, and feed rate) on the value of surface roughness, material removal rate, tool tip temperature, machining time and tool wear. Finally, after the experiment, the optimal parameters are determined that give the lowest surface roughness value, tool wear rate, and highest MRR. The effect of cutting force, machine vibration, tool geometry, and tool material on end responses was not investigated in this study. This was due to the difficulties of taking into account all parameters at once, as well as the lack of materials, machines and equipment with the required specifications.

1.9. Structure of the thesis

This thesis entitled as "Experimental Study and Optimization of Cutting Parameters during Dry Turning of AISI 0126 Steel" is organized from five chapters.

Chapter one presents introduction about the thesis which includes introduction to selected workpiece and cutting tool; conditions of machining processes; optimization methods; problem of statement; motivation for the study; significance and objectives of the study; and finally, scope and limitation of the study are included. Chapter two provides an overview of previous research works related to this research. Chapter three discusses the materials and methodologies used in this research study. This includes detailed information of work piece and cutting tool used, machines and equipment used, and the experimental procedure followed. Chapter four presents the key findings of experimental investigations with a detailed discussion. It looks at how cutting parameters (spindle speed, depth of cut and feed rate) affect surface roughness, material removal rate, tool tip temperature, tool wear rate and machining time in dry turning of AISI 1026 steel. Chapter five summarize and analyzed the experimental investigations conducted during the study, and proposed a recommendation and future work for further studies.

CHAPTER-2

LITERATURE REVIEW

2.1. Introduction

The most emerging requirements of the current metal cutting processes are to increase the material removal rate with better surface finish, high machining accuracy, and minimum tool wear rate. For every machining industry, selection of optimal cutting parameters is an important issue to enhance the quality of machined products, increase production rate and reduce machining costs. Researchers have been trying for years to capture the optimized set of input parameters and distinguish the effect of each input parameter on a particular output. In this section, different works by previous researchers were presented and after reviewing their work in deep research gap was identified.

2.2. Turning operation

Turning is a machining process in which single point cutting tool moves along the rotating workpiece to produce the required shape. Turning can be done manually, in which the operator continuously supervises the work, or it can be done by using automated lathe which does not requires continuous supervision of the operator. When turning operation is done, the workpiece rotated on its own axis and the cutting tool is traversed along 1,2, or 3 axes of motion to produce precise depths and diameters. Turning can be either on the inside of the cylinder (known as boring) or on the outside to produce various geometries. It is carried out on a lathe, one of the oldest machine tools, and produce different operations like taper turning, profiling or external grooving, straight turning etc.

2.3. Methods used in optimizing machining parameters

Optimization in machining processes is taken as an essential role for persistent enhancement of end product quality and activities include, modelling of input-output and in parameters relationship, and determination of optimal machining parameters (Goyal *et al.*, 2016). There are various methods developed by researchers in optimizing of machining parameters. These parameters fall in to two main categories as shown in Fig. 2.1.

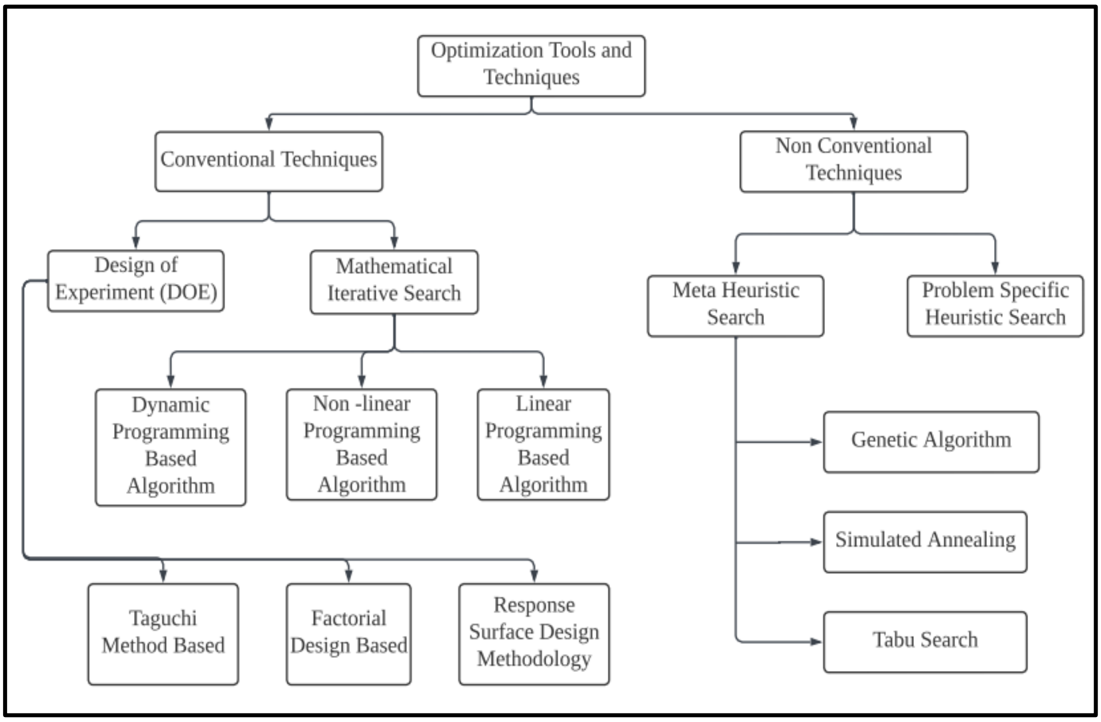

Figure 2.1.Types of optimization techniques (Kirubel, 2021).

2.3.1. Conventional techniques

Design of experiments (DOE)

Fisher established the Design of Experiments (DOE) in the 1920s as a statistical method for studying the effect of several factors at the same time. DOE is a statistical strategy for obtaining predictive knowledge of a multi-variable, complex process with a small number of trials. Commonly used conventional optimization techniques are explained here according to (Babu *et al*., 2006). Analysis of Variance (ANOVA) is commonly used conventional optimization techniques and it is a statistical procedure and hypothesis-testing tool that examines the variances of samples taken to evaluate the equality of two or more population means. In most experiments, a large amount of variation (or difference) suggests that the research yielded a noteworthy result and Taguchi has envisioned a new way for designing experiments (Taguchi optimization technique) that is based on well-defined standards. To establish a robust process and outcome for the best product quality, Taguchi method includes methods for system design, parameter design, and tolerance design. The other conventional technique is RSM (response surface methodology) and it is a set of mathematical and statistical approaches for analyzing data. The goal is to improve the response (output variable) that is influenced by a number of independent variables (input variables). An experiment is a sequence of tests, known as runs, in which input variables are changed to determine the causes of changes in the output response.

Davis *et al*., (2012) optimized cutting parameters during dry turning of mild steel using HSS cutting tool. The optimization was carried out utilizing feed, spindle speed, and depth of cut. Taguchi optimization approach, ANOVA, and Signal to Noise ratio (SNR) are utilized to identify the best combination of cutting parameters result in lowest surface roughness value. The authors concludes as feed rate had a significant factor. Asilturk and Akkus (2011) used Taguchi method for optimizing turning parameters to attain minimize surface roughness. The effects of cutting speed, feed rate, and depth of cut on surface roughness were investigated using the statistical methods of signal to noise ratio and analysis of variance. Results indicated that feed rate was the most significant factor affecting surface roughness.

Ashisharao *et al*., (2018) optimization of process parameters for machining of mild steel EN 18 by Response surface approach was the title of the study presented. The research examines parametric optimization of Mild Steel (EN18) on CNC MAX MILL machining with constant coolant flow and using cemented carbide as the cutting tool. Cutting parameters (feed rate, cutting speed, and depth of cut) were adjusted to achieve higher rate of material removal while maintaining low level of surface roughness. With the help of Design of Experiment, Response Surface Method evaluated the experiment data. The different parameters that have a significant impact on values of surface roughness and material removal rate are shown using ANOVA. It is found that optimal solution of MRR and Roughness found at spindle speed of 4186 rpm, depth of cut of 0.60 mm and feed rate of 1831 mm/min.

Somashekara (2012) works on the title "Optimizing Surface Roughness in Turning Operations Using Taguchi Technique and ANOVA”. Finding the best combination of turning variables (Cutting speed, Feed, and Depth of cut) that produces the best surface quality is the goal of this study in working with Al 6351-T6 alloy and uncoated carbide inserts. Models were created using a variety of statistical modeling techniques, including RSM and Genetic Algorithm (GA). In this study, the researcher used regression technique to create a model that predict surface roughness. Taguchi technique was also used to optimize the process parameters. To find important parameters impacting surface roughness, SNR and ANOVA analysis were used.

Makadia and Nanavati (2013) studied the effect of turning parameters, i.e., nose radius, feed rate, cutting speed, and depth of cut on surface roughness of AISI 410 steel. DOE has been used to study the effect of parameters. Surface roughness predictor mathematical model was developed related to these parameters, also their effect on surface roughness was investigated using RSM method. To determine the optimal combination of cutting parameters that gives better surface finish, Response surface contours were constructed. The result from developed prediction model shows that the main factor was feed followed by nose radius. The result shows increasing the feed rate and decreasing tool nose radius result in increasing of surface roughness of machined workpiece. The mathematical model developed was verified by doing the experiment and after the experiment it was seen as the model was valid with an error of 6%. Khamel *et al*., (2012) built a mathematical model to evaluate machining parameters using Response surface methodology considering process parameters such as cutting speed, depth of cut, and feed rate in hard turning of AISI 52100 bearing steel with CBN tool. In this work tool life, surface roughness, and cutting pressures was also studied. The surface roughness is heavily influenced by the feed rate and cutting speed.

2.3.2. Non-conventional optimization techniques

Cutting conditions in machining operations can be optimized using unconventional ways. Some previous works of optimization using non-conventional techniques are viewed under this topic.

Zain *et al.,* (2010) used a genetic algorithm in assessing the optimal cutting conditions for minimum surface roughness. A regression model is used to define goal work. From the result it was observed low feed rate, high cutting speed, and high rake edge lead to bring down surface roughness. Marko *et al.* (2014) presents the way of getting optimal cutting parameters in turning of a carbonized steel using non-conventional optimization technique particle swarm algorithm for surface roughness, cutting force and tool life. The research done on computer numerical control (CNC) machine and the input parameters are surface speed (m/min), feed rate (mm/rev), and depth of cut (mm). The output parameters are surface roughness R (μm), cutting force F (N), and maximal tool life T (min). Dynamometer Kistler 9257 was used to measure the cutting force and Mitutoyo roughness measuring unit SJ – 201P has been used to measure the surface roughness of the work part. Carl Zeiss microscope with magnification of 30x and resolution of 0.0001 mm was used to measure the usage of the cutting tool.

Fu *et al.,* (2012) advanced the cutting parameters during high-speed milling of NAK80 shape steel. Taguchi's technique was applied to do the experiment. The ideal cutting parameters were acquired utilizing grey relational analysis. The result shows that that grey relational analysis combined with principal component analysis could effectively anticipate the optimal combination of cutting parameters, and the proposed methodology can be a helpful tool to reduce the cutting force. Yan and Li (2013) presented a multi-objective optimization strategy dependent on weighted grey relational analysis and RSM to upgrade the cutting parameters during milling of medium carbon steel with carbide tools to accomplish the maximum material removal rate, minimum surface roughness, and minimum cutting energy. The experimental results showed that gray relational analysis (GRA) combined with RSM is a helpful device for multi-objective optimization of cutting parameters.

2.4. Effect of cutting parameters on surface roughness

Surface roughness and Material removal rate forecasting plays a major role in manufacturing industry for appropriate control and planning of machining parameters and optimization of cutting conditions. Surface roughness is a prime attribute in assessing surface quality of the machined product that is counted in the machining drawing and it's mostly related to right performance of a work part (Dolaimy, 2016). Even if surface roughness has as significant effect on the life and utility of a machined component it is difficult to control it completely due to its dependence on several process parameters and various uncontrollable factors (Dhar *et al*., 2007). Material removed from the work piece per unit time is called material removal rate and it can be calculated by the weight difference before and after machining operation was done or can be calculated from the volume of material removed. In machining operation higher MRR is desirable for production of large batches within shorter period of time. Like surface roughness, MRR is also influenced by different cutting parameters and in this section the effect of cutting parameters on surface roughness and MRR are reviewed from the work of previous researchers.

Goyal *et al.,* (2016) experimentally investigated turning operation performed on AISI 1020 mild steel using carbide insert cutting tool. The influence of three parameters, namely cutting speed, depth of cut and feed rate on MRR and surface roughness was investigated. MRR and surface roughness are optimized using a Taguchi method. The result revealed that cutting speed was most significant factor that influences the surface roughness followed by feed, and in case of material removal rate; the most significant factor was depth of cut followed by cutting speed. The combination of both surface roughness and material removal rate were most significantly affected by depth of cut followed by feed. Suleiman and Bashir (2010) investigated the effect of cutting parameters (speed, feed and depth of cut) on the surface roughness during turning of mild steel. The experiment was done using a Box Behnken experimental design method and ANOVA was used to analysis the effect of cutting parameters on surface roughness using multiple linear regressions. The researchers conclude that, feed rate had most significant parameter affecting the surface roughness followed by cutting speed and turning with high spindle speed minimizes the surface roughness of work part in opposite to the feed rate. Confirmation test were done to validate weather the mathematical model is good and the result of the confirmation test shows that the model developed for surface roughness is accurate and the model can be used to forecast the surface roughness.

Jha (2014) analyzes effect of process parameters (cutting speed, depth of cut and feed rate) on volume of material removed using Taguchi orthogonal array method. A mild steel bar was selected as the workpiece and TIN-coated carbide tools are used to undertake the turning operation. The significant parameters that affect the volume of material removed are identified using analysis of variance. ANOVA result indicated that feed rate had the most significant parameter that affects the rate of material removed than depth of cut and cutting speed.

Dolaimy (2016) conducted its work on the effect of cutting parameters on the surface roughness in a turning operation to determine the optimal parameters in order to get better surface roughness within short cutting time and minimum cost. In this work different machining parameters were used as inputs such as depth of cut, cutting speed, feed rate and usage of cutting coolant and surface roughness was measured after the experiment was done on a steel turned work piece which was carried out on a computer-controlled (CNC) and conventional lathe machine with a carbide tool as a cutting tool. The result revealed that cutting parameters, using of coolant and the machine tools significantly influence the surface roughness. Surface roughness was increased when the feed and depth of cuts are increased and surface roughness decreased when cutting fluid is used, and cutting speed is increased. Also, the result shows surface roughness is increased when it's done on a conventional lathe machine than CNC machine using the same cutting parameters.

Singh *et al.*, (2018) works on Optimizing of cutting parameters in dry turning of Al5083/B4C composite. Experimental work was performed on Al5083 metal matrix composite reinforcement of 7% B4C. Cutting tool used to do the experiment was High Speed Steel

(HSS). In the present experiment the turning parameters such as cutting speed, feed rate and depth of cut are being optimized by considering the constant length of material being machined. The experiments conducted as per L25 orthogonal array (OA) and their result are used to develop a linear regression model. The investigation showed that increasing the speed and depth of cut increases the MRR and depth of cut shows an intermittent effect with an increase in feed rate. Surface roughness increases with an increase in depth of cut and feed rate, and shows the intermittent effect with speed. Change in temperature increases with increase in speed and depth of cut.

Harsh *et al*., (2014) had studied the surface roughness features and power utilization of surface produced in turning of EN-31 alloy steel. The experiment was done by using coated tungsten carbide cutting tool (TiN+Al2O3+TiCN) with variety of cutting parameters. Spindle speed, depth of cut, and feed rate are the parameters taken to do the experiment and the result showed that as these three parameters significantly affects the surface roughness and power consumption in turning of EN-31 alloy steel using coated carbide cutting tool.

Jaiganesh *et al*., (2017) optimized metal cutting process parameters for multiple responses such as metal removal rate, chip thickness ratio and surface roughness for input parameters (depth of cut, cutting speed and cutting time) with increased quality and reduced cost on commercial mild steel using the Taguchi method. In this research, a carbide-tipped general-purpose cutting tool is used. Nine experiments were conducted based on an orthogonal array and ANOVA was applied to identify the factor that has a significant effect on the machining operations. The optimum values that achieved better surface roughness are 900rpm speed, 8.3 seconds and 1-mm depth of cut. From the finding, the optimum values that achieved better chip thickness ratio are 900rpm, 8.3 seconds and 1.3-mm depth of cut. The optimum values gave better MRR are 2000 rpm, 8.3 seconds and 1-mm depth of cut.

Butola *et al*., (2017) investigated the effect on surface properties of mild steel bar using a high-speed steel cutting tool while turning operation by comparing wet and dry turning. The experiment was done by taking six pieces of mild steel and on the first three pieces, dry turning was performed and on the other three, a flooded turning operation was performed. Surface roughness was measured by a contact-based profilometer (diamond stylus) and the result of surface roughness obtained after dry turning was 2.98 – 3.43 μm and surface roughness obtained after wet turning was 1.36 – 2.10 μm. The result revealed that the surface roughness minimized when the work piece is machined in a wet condition.

Yan *et al.,* (2015) reviewed previous works on the effect of cutting fluid applied in machining or cutting of metal. The reviewed paper suggests that fluid should be used in machining of metal metals to get a good surface finish, enhance life span of cutting tool and improve machining efficiency by decreasing cutting temperature, and friction between the work piece and the cutting tool. According to this paper, the disadvantage of the cutting fluid is the problem of matching the work piece with the flood. A lot of researches had been done to reduce the use of cutting fluid due to high strengthening awareness of environmental impact and to minimize high cost required to get the cutting fluid. The summarized conclusion revealed that even if the use of cutting fluid has a wide advantage to make machining operations, it is necessary to develop a new method of machining operation to minimize the effect of cutting fluid on the environment and to reduce the total cost of work by developing new kinds of green cutting fluids or by taking the work in dry condition.

Tulasi *et al.,* (2018) examined a new approach to optimize surface roughness in turning operation using Taguchi parameter design technique. Reducing the variation between actual surface roughness value and required surface roughness value that is caused due to machining parameter during machining is the main work that is done by this article. The critical conditions like feed, spindle speed and depth of cut are selected for turning of EN24 steel work and carbide tipped cutting tool is used in the conventional lathe machine. In this study, L9 orthogonal array was selected, and the minimum surface roughness of cylindrical work piece was investigated. Finally, the introduced optimization technique successfully verified the optimum cutting parameters which give lower surface roughness.

Chowdary *et al.,* (2018) focused on optimization of surface roughness and material removal rate to implement quality of machined product by optimizing turning process under different machining parameters using Taguchi technique of optimization in turning of mild steel in dry condition. The cutting tool used was coated cemented carbide tool. The experiment was done with three process parameters (cutting speed, depth of cut and feed rate) each of with three levels. The experiment was conducted by L9 OA. SNR and ANOVA were employed to find the optimal surface roughness and material removal rate. The outcome of the work revealed that minimum surface roughness is achieved on 630 rpm spindle speed, 0.4 mm/rev feed rate and 0.6 mm depth of cut. The best combination of input parameters in which maximum MRR or defect free turning was at 630 rpm of spindle speed, 0.6-mm/rev feed rate and 0.8-mm depth of cut. The result shows surface roughness largely affected by feed rate followed by depth of cut and cutting speed.

Moganapriya *et al*., (2018) investigated the influence of cutting parameters and coating material on material removal rate and surface roughness in the turning process of AISI 1015 mild steel using the Taguchi method. In this study the cutting parameters used were, coating material, depth of cut, cutting speed and feed rate with TiAlN/WC-C, TiAlN coated tool while the turning operation is done on JOBBER XL CNC turning center with 7.5 KW spindle power. Surface roughness was measured by Mitutoyo SJ-410 surface roughness apparatus and material removal rate is calculated by

$$MRR = [\text{Mass (Before)} - \text{Mass (After)}] / (\text{Time} * \text{Density}). \qquad (2.1)$$

L9 orthogonal array was used to determine the optimum material removal rate and minimum surface roughness. The best combination of cutting conditions for surface roughness were determined as depth of cut of 1 mm, cutting speed of 550 m/min, feed rate of 0.05 mm/rev, and multilayer deposited as TiAlN/WC-C. From the ANOVA result, it's viewed that depth of cut and coated material deposit were the most significant cutting conditions that influence surface roughness also in case of material removal rate coating material deposit had a significant effect on the volume of material removed.

Panneerselvam *et al.*, (2021) analyzed cutting tool performance of powder metallurgy alloy steel, Fe- 0.5 %, C-2 %, Cu-2 %, Mo-2 %, Ti as a cutting tool under the turning of copper material using a conventional lathe machine. Cutting speed, feed rate and depth of cut are selected as working parameters and Taguchi experimental design matrix was used to conduct the experiment. Evaluated surface quality of the work part is used to assess the performance of the tool. The experiment was conducted by turning the same work piece and comparing the result when it was machined by a conventional high-speed steel tool and powder metallurgy tool. Surface roughness was measured by Mitutoyo portable surface roughness measuring equipment with an accuracy of 0.001 microns. The optimized result in which smaller surface roughness attained was at, V = 43.175 m/min, f = 0.43 mm/rev and D = 0.1 mm. The final result revealed that, powder metallurgy exhibits good performance compared to conventional high-speed steel tool or the surface roughness value of powder metallurgy tool was lower than high speed steel tool.

Clares *et al.*, (2015) proposed an experimental methodology for evaluating work piece surface integrity in dry turning of strategic alloys such as aluminum and titanium used in the aerospace industry. The developed relationship can be used to determine the effect of manufacturing procedure which can affect the final properties of the work piece material. A conventional lathe machine was used to machine the workpiece and the absence of the flood or lubricant promotes the environmental sustainability of the process. Neutral turning inserts ISO DCMT 11T3308 were selected as a cutting tool and different turning parameters as 0.03-0.20 mm/min, 0.50mm and 588.00 per minute for feed rate, depth of cut and spindle speed respectively. The result of the experiment enabled generation of predictive behavior models, favoring the selection of most suitable machining conditions of manufactured components.

Karthik *et al.,* (2020) works on optimizing of EN 31 bearing steel using CBN insert in dry turning condition to enhance the surface roughness. The effect of the cutting parameters on the surface roughness was studied and optimum cutting conditions were obtained. Taguchi design and ANOVA were used to get the optimal cutting parameters. The resalt revealed that for different combination of cutting speed and depth of cut increasing the feed rate causes in an increase of surface roughness. Therefore, feed is the most influencing and dominant parameter for the improvement of surface roughness. The optimal cutting parameters obtained from the Taguchi L9 Orthogonal array and main effect plots are cutting speed(v) = 100 m/min, Feed(f) = 0.04 mm/rev and Depth of cut(d) = 0.2 mm.

Qehaja *et al.,* (2015) studied the effect of cutting parameters such as feed rate, nose radius and cutting time on surface roughness in dry turning of cold rolled steel C62D using SNMM coated tungsten carbide inserts (Sintal) cutting tool. The outcome of the paper shows that with the lowest cutting time and feed rate, increasing of nose radius leads to decreasing of surface roughness and it is found that the parameter that has the most significant effect on the surface roughness is feed rate followed by nose radius and cutting time respectively. According to the paper, to get better surface finish, it recommends the lowest level of feed rate, highest level of depth of cut and cutting speed to be used during the operation.

Jha (2014) worked an experiment on dry cutting of hardened AISI 4340 steels. The parameters taken on this research are speed, depth of cut and feed. Coated carbide inserts cutting tool was used to machine the workpiece. For the experimental design a full factorial design of experiment was selected and to analysis the main significant factors ANOVA was employed. From the ANOVA result it can be observed that feed is the main significant parameter followed by cutting speed on the surface roughness. Feed affects the surface roughness by 60.85% and cutting speed affects it by 24.6%. The best combination of cutting parameters that gives the optimal values for this experiment was when cutting speed was adjusted on 150 m/min and the feed is adjusted as 0.05 mm/rev.

Phalke (2019) optimized the surface roughness of Austenitic stainless steel AISI 304 in dry turning operation using Taguchi design method. The size of the work piece used was 80-mm diameter and 300-mm long round rod. An orthogonal array (3 levels L9 OA), ANOVA, and SNR were used to investigate cutting parameters of the work piece using TICN and TIC coated tungsten carbide cutting tool. Surface roughness measurement was taken by cut-off (2.5mm) and piezoelectric stylus. From the result, it was concluded that feed rate, cutting speed, and depth of cut affects the surface roughness by 51.84%, 41.99%, and 1.66% respectively.

Torres *et al.*, (2015) experimentally investigated the effect of different machining parameters on the surface roughness during dry turning of 2030-T4 aluminum alloy. The parameters taken were tool radius, cutting speed, depth of cut and feed rate. Design of experiment (DOE) was used to choose the optimal cutting condition that results in minimum surface roughness. The experiment was carried out on a numerically controlled Danobar-45 lathe machine which has 5550 rpm spindle speed and 19.5 kW power. Coating of titanium nitride) was used as a cutting tool to perform turning operation. The surface roughness was measured by an electronic Rugosimeter with mobile stylus (ALPA RT-70). The experimental result revealed that in dry turning of aluminum alloy used as a work piece, the interaction of depth of cut and feed rate have a significant effect on the surface roughness value. In the face operation it was found that feed rate was the most significant factor influencing surface roughness.

Awopetu and Ayodeji (2008) studied the type of chip formed during turning of different metals. Cutting activities were performed on a universal lathe machine, making turning actions on stainless steel, mild steel, and titanium. The experiment was done in dry condition for the three of work pieces. In doing this experimental work cutting feed, is set to 5 mm/rev; Cutting speed, is set to between 2-120 m/min; and cutting depth, is set to 3 mm. uncoated carbide cutting tool is used to cut the workpieces. The result revealed that when the figure of the chip is seen under a microscope (X1500), a chip root from mild steel demonstrates the creation of a continuous chip. This further proved that mild steel will naturally have continuous chips while turning under normal conditions.

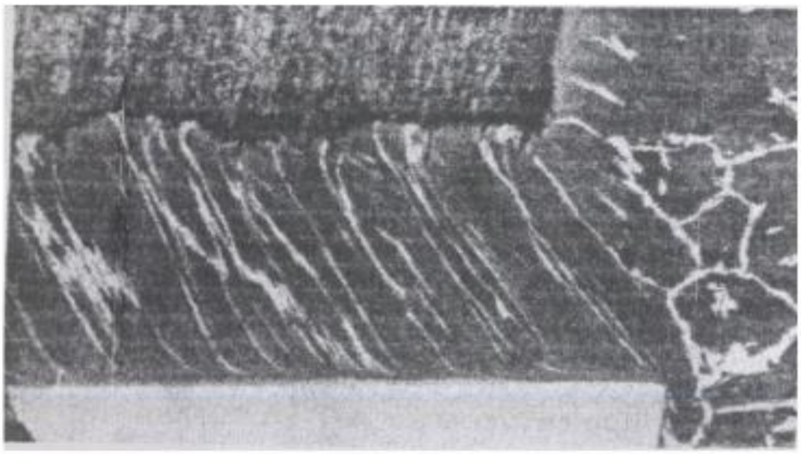

Figure 2.2.A mild steel chip root demonstrating the creation of a continuous chip (x 1500) (Awopetu and Ayodeji, 2008)

When the cutting speed had to be greater than 90 m/min, other type of chip is generated, the tool wear had to be significantly greater than the recommended amount, and the machine's resonance range (level) had to be surpassed and in this circumstance, a segmented chip, also known as a discontinuous chip, will be formed. This form of chip from mild steel is not useful.

2.5. Effect of cutting parameters on tool tip temperature and tool wear

During machining operations heat is generated due to the friction occurred between the cutting tool and the machined workpiece. The generated heat at the cutting zone has a strong effect on the tool wear, workpiece surface quality, produces hot chips that cause safety hazards to the machine operator, and can cause inaccuracies in work part dimensions due to thermal expansion of the work material. In metal cutting industry the most regrettable trade mark is wear of the cutting device (Prajapati *et al*.,2019). Tool wear is continuing failure of cutting tool due to regular machining operation like turning. The friction occurred between the cutting tool and the workpiece leads to generation of high temperature and this temperature affects the cutting tool and results in tool wear. Tool life refers to the amount of machining time that the cutting tool provides the intended and desirable results. Tool life is critical in machining since replacing and resetting a tool wastes a lot of time and cost. Increased tool life leads to increased productivity and lower machining costs. Tool life assesses the performance of a cutting tool. The amount of satisfactory performance or service provided by a new tool or a cutting point until it is pronounced failed is referred to as tool life. Wear criteria are usually used in assessing tool life and mostly, flank wear is considered, since it largely affects the stability of the cutting edge and consequently the dimensional tolerance of the machined work surface (Ginta *et al*., 2009). The effect of cutting parameter on tool tip temperature, tool wear and tool life is reviewed from the work of previous researchers in this section as follows.

Dasgupta and Mukherjee (2016) studied and optimized the effect of machining parameters on tool life under wet turning mild steel with brazed carbide cutting tool. Nine experiments were conducted taking three factors (spindle speed, feed and depth of cut) each having three levels. The level of importance of machining parameters on the tool life is examined by ANOVA and also to predict the tool life, a mathematical model based on multiple regression analyses was developed. The result shows that the optimal combinations of parameters are at the lower level of spindle speed, depth of cut and feed rate. The factor that had the most significant effect on the tool life was feed rate followed by spindle speed and depth of cut respectively. The Statistical results (at a 99.5% confidence level) show that the spindle speed, feed rate and depth of cut affects the cutting process by 25.42%, 65.98% and 3.97% in the turning of mild steel by brazed carbide cutting tool, respectively.

Yousuf and Salim (2018) aimed to experimentally investigate the relation between cutting speed and tool wear rate. Stainless Steel (304) and Aluminum cylindrical rods of 30 mm diameter and 60 mm long are selected as workpiece and Tungaloy carbide T9115 cutting tool was used. The findings re-affirm that increasing cutting speed leads to greater cutting tool wear and shorter tool life. Sharma *et al*., (2013) forecasts the effects of cutting parameters (rake angle, temperature, feed rate, depth of cut, and cutting speed) on tool life. From the result it was observed, as tool rake angle increases, the cutting force falls. Cutting force tends to rise as the feed rate increases. The decrease in tool chip friction is caused by increasing the absolute value of negative tool rake angle and cutting speed. The temperature of the tool tip rises as the cutting speed rises. Cutting forces are reduced as the positive rake angle increases, implying that less force/power is required.

Yemul *et al.,* (2021) observed that have observed that the type of CBN tools used, composition of the machined part and cutting conditions decides the wear pattern occurred on the workpiece. From their work, they concluded that abrasion, diffusion, and adhesion are the mentioned to be They also concluded that generally, adhesion, abrasion and diffusion are figured to be main tool wear mechanisms in CBN hard turning. A few basic mechanisms rule of cutting tool wear is:

i. *Diffusion wear*: taken by chemical loading cutting material and on tool.
ii. *Oxidation wear*: crusades gaps to occur in coated film and outcome in a loss of the coating at elevated temperature.
iii. *Fatigue wear*: is a thermo-mechanical result and leads to the breakdown of the edges of cutting tool.
iv. *Adhesive wear*: happens at devalued machining temperatures on the chip face of tool and leads to shaping of a built-up edge, and the perpetual break down of the built-up edge and tool edge itself.
v. *Abrasive wear*: affected by hardness of the work material and is restrained by content of the cutting material

Abou and Kops (2017) concentrated on machining of mild steel round bar (AISI 1018) by using lathe machine at various feed rates, depth of cut and cutting speeds under dry condition and tasted the wear and temperature of cutting tool. A data acquisition system was built to measure the cutting temperature while turning the work piece. The cutting tool used is cutting inserts (TNMG160404-MA) from Mitsubishi Tooling, and the inserts had multiple layers of coatings that consist of Al_2O_3 and TiCN. To control the chips during the cutting process, the cutting inserts contained a chip breaker. The experimental result showed that highest value of depth of cut and cutting speed significantly causes high surface temperature and a maximum flank wear of 199 µm was obtained. Increasing the feed rate didn't show a negligible effect on the surface temperature and the lowest wear of 27 µm was obtained. In this paper cutting tool inserts were examined under a scanning microscope to measure the tool wear in each individual experiment.

Khan *et al.,* (2015) carried out its work under the title "experimentally investigating the wear and surface quality of EN8 steel while turning it in a flooded and dry condition" to determine if dry cutting can be a cost-effective solution. The outcome shows both dry and wet conditions have their own benefits in relation to the intended application of the part, but mostly dry cutting provides surface roughness as good as the wet turning when it's finished by turning and with an acceptable range of tool wear rate. The paper recommends dry condition should be employed in most circumstances for rough cutting with knowledge of slight increase in tool wear and shorter life but with reduced environmental hazard due to the use of a cutting tool and low manufacturing cost.

Naik and Magdum (2018) they are tried to relate cutting force and tool wear in turning of EN 8 steel to assess the tool wear effect. In this work different values of cutting forces are applied and the wear occurred on the tool is sawn as a response variable. Developing an online observation system was the main objective of this work. This work gives suggestion as at what the tool should be changed by identifying different criteria's to effectively specify and determine rapid tool wear during machining of EN 8 steel. The finding showed that as the tool wear increases the cutting forces are also increases. Singh *et al*., (2013) experimental investigates the effects of cutting parameters like spindle speed, feed and depth of cut on the hardness of EN-9 steel. The relationship between cutting parameters (cutting speed, depth of cut, feed) and the performance measures (work-piece surface temperature) are expressed by the performance level for any parameter levels. The significant parameters for work-piece surface temperature were cutting speed, depth of cut and feed in which feed having the highest rank. Surface temperature is maximum (38.20 ^{o}C) when 388 rpm, depth of cut 0.50 mm and feed 0.9 mm, which is worthless. The significant parameters for optimum work-piece surface temperature are rpm (239), depth of cut (0.25 mm) and feed (1 mm).

Usca *et al.,* (2021) investigated the effect of the machining parameter on tool wear, surface roughness, chip formation and cutting temperature of copper composite reinforced with Mo-SiCp (Cu/Mo-SiCp) hybrid composite during dry turning on a conventional lathe machine. After the experiment was done, it proved that particle additive ratio was the most significant factor that influences surface roughness, tool wear, and cutting temperature.

2.6. Effect of cutting tool geometry on end responses

Cutting tools have different shapes, each of which are labelled by their angles or geometries. Selection of the right type of cutting tool geometry is a critical for specific job to be done. There are seven parameters that define the geometry of a cutting tool. They are; Back rake angle, Side rake angle, End relief angle, Side relief angle, End cutting edge angle, Side cutting edge angle, and Nose radius. Effect of cutting tool geometry on end response like surface roughness, tool wear and tool life is reviewed in this section as follows.

Karim *et al.,* (2013) conducted an experiment during machining of Al6061 aluminum alloy. Positive and negative rake angles were used to investigate surface finishing and tool wear. The rake angles were adjusted from positive to negative values while the machining parameters remained fixed. The surface roughness values and flank wear were measured using a Handysurf surface roughness tester and a Microscope Motic Images Plus at every

200 mm tool travel distance. According to the results, flank wear increases as the rake angle increases. When the rake angle is 15, the flank wear is at its peak. The plot of flank wear versus cutting length reveals a linear connection with a same slope, indicating that cutting tool wears at a similar rate. As a result, both rake angles have the same effect on flank wear throughout the turning process. The rake angle has an inverse relationship with the surface roughness value. Surface roughness decreases as the rake angle is raised. The findings of this study can be used to optimize machining parameter settings in order to get the minimum value of surface roughness with the least amount of flank wear.

Senthilkumar and Tamizharasan (2014) studied the effect of tool geometry on the surface roughness of in turning of AISI 1045 steel. Uncoated cemented carbide tool was selected as a cutting tool that has a 1433 BHN and used as a general machining operation. Geometrical parameters of cutting inserts such as insert shape (including angle of cutting edge), nose radius and relief angle were taken for analysis by maintaining other machining parameters constant. Output characteristics such as surface roughness, flank wear, and material removal rate are analyzed by Taguchi design of experiment using analysis of variance and signal to noise ratio. Nine cutting tools inserts were used with different shapes, nose radius and relief angle to conduct the experiment and L9 orthogonal array was chosen since it was suitable. The experimental result shows that the cutting insert is the most significant factor. The contribution of cutting insert is found to be 45.27% and the contribution of nose radius is by 36.37%. Relief angle is the least significant factor that contributes by 5.28% towards the response.

Singh *et al.,* (2016) observed that finish turning of hardened AISI 52100 steels is affected by tool nose radius. At various machining settings, the surface quality, tool wear, cutting forces, was assessed. The results revealed that larger tool nose radii produce a smoother surface quality compared to a narrow nose radius. Radius of the nose White layers only appear on new tools with aggressive feeds (0.3 mm/rev) and small tool sizes. The greater the radius of the nose, the deeper the white layers get. Even with mild feeding, white coatings emerge on worn instruments. Large nose radius leaves deeper white layers (0.05 mm/rev). The larger the radius results in a bigger uncut chip thickness as a result, a larger shear plane heat source that may cause induction for deeper white layers. Temperature analysis at machined surfaces demonstrates that the higher the tool nose radius, the deeper the temperature penetration due to a shorter transition-material zone from the cutting edge to the final machined surface, for worn tools where wear-land sliding is the primary heat source.

Usman (2012) impact of tool rake angles on tool life has been examined on turning of bright mild steel with rake angles 0°, 5°, 10°, 15°, & 20° with constant relief angle of 80^0, using a HSS of 18 mm side as the cutting tool. Soluble oil is used as coolant to minimize friction between work part and cutting tool. This objective is to investigate electricity saving possibilities during tool regrinding. When tool material gets worn, regrinding them wastes valuable production time and effort. It is observed that choosing appropriate rake angle, extends tool life and conserve time and energy. The result revealed that a rake angle of 20 provided the longest life of the tool, generated continuous chips, and provided the greatest surface finish while turning of bright mild steel using high speed steel cutting tools.

Lo (2000) this researcher used finite element method, and investigated turning effect of a work part under various rake angles. This study uses the elastic plastic finite element method to evaluate the impact of tool rake angle on the chip and machined object during the precision cutting operation. Cutting simulations were run at various tool rake angles to investigate the impact of tool rake angle on chip geometric forms, cutting force, residual stress, equivalent stress distribution, and the surface of the machined work piece. The researcher concludes that;

- As the tool rake angle increases, the cutting force falls. The magnitude of cutting-force decrease is particularly seen in this article when the rake angle grows from 10 to 15^0. When the rake angle is increased from 15 to 20^0, the cutting force is only slightly reduced.
- As the tool rake angle increases, the top of the chip shape gets smoother, and the difference between the chip thickness and the undeformed chip thickness diminishes.

2.7. Summary of literature

Finding optimum values of cutting parameters on different materials was done by many researchers, but still now there are a number of materials on which the same work has not been performed. As it is seen from the literature above, most of the researchers focused on studying the effect of cutting speed, feed rate, tool geometry and depth of cut on the surface roughness, material removal rate, tool temperature, cutting force and tool wear in turning of different materials under different conditions. Most of the works concluded as feed rate, depth of cut, and cutting speed have a significant effect on the surface roughness, material removal rate, tool temperature and tool wear in turning of different materials.

Table 2.1. Summary of literature review

No.	Author (year)	Material	Cutting tool	Input parameters	Response variables	Optimization technique
1	Goyal *et al.*, (2016)	AISI 1020	Carbide inserts	Speed, Depth of cut & Feed rate	MRR & Ra	Taguchi
2	Jaiganesh *et al.*, (2017)	Mild steel	Carbide tipped	Cutting time, Depth of cut, Cutting speed	Chip thickness, MRR, Ra.	Taguchi
3	Dasgupta, and Mukherjee (2016)	Mild steel	Brazed carbide	Speed, feed and depth of cut	Tool life	Taguchi
4	Butola *et al.*, (2017)	Mild steel	HSS	Depth of cut, speed, &feed in dry and wet turning	Roughness	RSM
5	Hossein, and Kops (2017)	AISI 1018	TNMG160 404-MA insert	Speed, feed and depth of cut	Wear and temperature of tool	RSM
6	Khan *et al.*, (2015)	AISI 1045 steel	Carbide tip	Rake angle, feed rate, and cutting speed	Tool T^o, cutting force and work specimen T^o.	Finite element simulation
7	Chowdary *et al.*, (2018)	Mild steel	coated cemented carbide	cutting speed, depth of cut and feed rate	MRR & Ra	Taguchi
8	Moganapriya *et al.*, (2018)	AISI 1015	TiAlN/WC-C, TiAlN coated tool	coating material, depth of cut, cutting speed and feed rate	MRR & Ra	Taguchi

2.8. Research gap

As a result of comprehensive review of work done by previous researchers, it is found that many researches have been carried out on optimizing surface roughness in machining different types of steel. Some research work has been done on optimizing low carbon steels and some of them shows contrasting results; Goyal *et al.*, (2016) observed that cutting speed was the most significant factor that influences the surface roughness, followed by feed, but Chowdary *et al.*, (2018) observed that surface roughness is principally influenced by feed rate followed by depth of cut. In case of AISI 1026 steel specifically, the optimization of cutting parameters on surface roughness, material removal rate, tool tip temperature, machining time and tool wear rate were not studied as well as not published. Hence, an effort was made to experimentally investigate the combined effects of cutting parameters (spindle speed, depth of cut, and feed rate) on surface roughness, material removal rate, tool tip temperature, machining time, and tool wear rate in dry turning of AISI 1026 steel with a carbide cutting tool, and optimization of the parameters were done using Taguchi method.

CHAPTER-3

MATERIALS AND METHODOLOGY

In this section selected type of materials and methods used to perform the experimental work are well described.

3.1. Material and Equipment's

3.1.1. Work-piece

The work-piece material used in this research was AISI 1026 steel. AISI 1026 is one category of low carbon steel that has carbon content of 0.22-0.28%. Many industries use AISI 1026 steel, as it is easily machined, welded and forged. It is used as structural steels in construction, bridges, rail way stations, industrial equipment's, shipping containers, commercial appliances, decorative items, chains, rivets, keys, bolts, shafts, food cans, car parts, piping, garden hooks, automobile exhausts, etc. This selected steel was machined in dry condition at different cutting parameters and the effect of cutting parameters was studied. For this study a round bar of AISI 1026 steel with 40 mm in diameter and 410 mm length was selected to do the experiment. This selected material was machined in dry condition due to advantages of dry turning in respect to environmental aspect and decreasing of overhead costs.

Figure 3.1. Image of selected workpiece material

Physical and mechanical properties of AISI 1026 steel is shown in Table 3.1.

Table 3.1. Properties and equivalent materials of AISI 1026 steel

<table>
<tr><td colspan="3">Properties</td><td>Metric</td></tr>
<tr><td colspan="4">Physical property</td></tr>
<tr><td colspan="3">Density</td><td>7.858 g/ cm^3</td></tr>
<tr><td colspan="4">Mechanical property</td></tr>
<tr><td colspan="3">Tensile strength</td><td>490 MPa</td></tr>
<tr><td colspan="3">Yield strength</td><td>415 MPa</td></tr>
<tr><td colspan="3">Bulk modulus (typical for steel)</td><td>140 GPa</td></tr>
<tr><td colspan="3">Shear modulus (typical for steel)</td><td>80.0 GPa</td></tr>
<tr><td colspan="3">Elastic modulus</td><td>190-210 GPa</td></tr>
<tr><td colspan="3">Poisson's ratio</td><td>0.27-0.30</td></tr>
<tr><td colspan="3">Elongation at break (In 50 mm)</td><td>15.00%</td></tr>
<tr><td colspan="3">Reduction of area</td><td>40.00%</td></tr>
<tr><td colspan="3">Hardness, Brinell</td><td>143</td></tr>
<tr><td colspan="3">Hardness, Vickers (converted from Brinell hardness)</td><td>149</td></tr>
<tr><td colspan="3">Machinability (based on AISI 1212 steel as 100 machinability. The machinability of Group I bar, rod, and wire products can be improved by cold drawing.)</td><td>75</td></tr>
<tr><td colspan="4">Equivalent materials to AISI 1026 carbon steel</td></tr>
<tr><td>ASTM A29</td><td>ASTM A510</td><td>ASTM A512</td><td>ASTM A513</td></tr>
<tr><td>ASTM A545</td><td>ASTM A576</td><td>ASTM A830</td><td>MIL F-20670</td></tr>
<tr><td>MIL S-24093</td><td>SAE J1397</td><td>SAE J403</td><td>SAE J412</td></tr>
<tr><td>ASTM A273</td><td>ASTM A519</td><td>MIL S-22698</td><td>SAE J414</td></tr>
</table>

3.1.2. Cutting tool

Cutting tools are used to separate chips from the workpiece to obtain the desired shape and size. In the selection of a cutting tool, different factors are taken into account and some of them are; the cutting tool material should be harder than the workpiece material to be cut, the cutting tool should be shaped so its cutting edge can easily penetrate the workpiece material, and the tool must be strong and rigid enough to withstand cutting force. In this research, carbide cutting tool inserts (TCMT 16T308-PM 4225) employed to machine the work piece. This triangular insert has three cutting edges per side, separated by 60^0. This carbide cutting tool was selected based on literature and industrial experience. It can used to machine steels and allows faster machining and leaves a better finish on metal parts, reducing the downtime required to change edges and is easily replaceable. Carbide cutting tools are widely used in the metal cutting industry for cutting of various types of metals, including steels and hard materials such as alloy steels, die steels, high speed steels, bearing steels, white cast iron and graphite cast iron, and most of the cutting tools used in modern industries today are carbide cutting tools (Sahin and Motorcu, 2005). Carbide is a binary compound of carbon mixed with another element. Carbide cutting tools have the following advantages: they are available, cost effective, ability to dissipate heat more than steel, last longer than steel, provide cleaner cuts and finishes, etc.

Figure 3.2. Image of carbide cutting tool used (TCMT 16T308)

Cutting insert identification: designations of cutting tool insert is shown as below. Designation TCMT16T308 is explained as follows.

The letters and numbers represent;

1. *Insert shape*: the first letter defines the shape of the cutting tool. In this case the first letter (T) represents the shape of the cutting insert is triangular.
2. *Normal clearance*: the second letter represents the normal clearance of the cutting tool. Letter C represents the selected cutting tool has a normal clearance of 7^0 .

3. *Tolerance class*: third letter in the box represents tolerance class and letter M represents tolerance of nose height (plus or minus 0.13mm), tolerance of inscribed circle (plus or minus 0.08mm), tolerance of thickness (plus or minus 0.13mm).
4. *Fixing and/or for Chip Breaker*: letter T represents as the cutting tool have one sided chip breaker and as the hole configuration is cylindrical.
5. *Insert Size*: two-digit number in the fifth box represents the size of the cutting insert and code 16 represents the length between two consecutive cutting edge is 16 mm and diameter of the inscribed circle is 16 mm.
6. *Insert Thickness*: code T3 represents the thickness of the insert from the bottom of the insert to the top of the cutting edge and the thickness is 3.97 mm.
7. *Insert Corner Configuration*: the last two-digit numbered shows as the nose radius of cutting tool is 0.8 mm.

3.1.3. Cutting tool holder

A tool holder is a short steel bar having a shank at one end by which it is clamped to a machine and a clamp at the other end to hold small interchangeable cutting bits. They are used to secure cutting tools or inserts in place during a range of processes, including facing, threading, and boring during work on a lathe. Tool holders usually attach to lathes through the tool-post. A STGCR2525M16 tool holder was used to perform the experimental work.

Figure 3.3. STGCR2525M16 tool holder; a) Side view b) Front view

Detailed specification of STGCR2525M16 tool holder is shown in Table 3.2.

Table 3.2. Specification of STGCR2525M16 tool holder

Description	Value	Description	Value
Shank width	25mm	Functional length	150 mm
Height of tool holder shank	25mm	Insert shape code	T
Direction of cutting	Right	Shank type	Square shank
Insert clamping system	S	Net weight	0.720 kg
Tool cutting edge angle	90^0	Functional width	32.0 mm

3.1.4. Machines and equipment's

A. Spectrometer

Spectrometer is a technical apparatus used to separate and size spectral components of a physical phenomenon. Spectrometer was used in this study to identify the chemical composition of the workpiece material. In this research work, Oxford Instruments PMI-MASTER Smart located at Ethiopian Technical University was used to study the composition of the work piece material.

Figure 3.4. Image of Oxford Instruments PMI-MASTER Smart

Chemical composition of selected workpiece

The composition of the workpiece is tested using Oxford Instruments PMI-MASTER Smart (available in Ethio technical university) to know whether the selected material satisfies the requirement or not. From the result, it is concluded that the material is mild steel with a carbon content of 0.265 %. The composition result is shown in the table 3.3 below.

Table 3.3. Chemical composition of AISI 1026 steel tasted

Chemical composition	Percentage (%)
Iron, Fe	98.989
Carbon, C	0.265
Manganese, Mn	0.613
Sulfur, S	$\leq$ 0.050
Phosphorous, P	$\leq$ 0.04
Others	$\leq$ 0.043

B. Lathe machine

Lathe is a machine that rotates a workpiece about an axis of rotation to perform turning, facing, cutting, drilling, knurling, etc., and they are used widely in industries. For this experimental study, a conventional engine lathe machine modeled as CU 630 which have spindle speed ranges from 50 to 1250 rpm was used to turn the workpiece material.

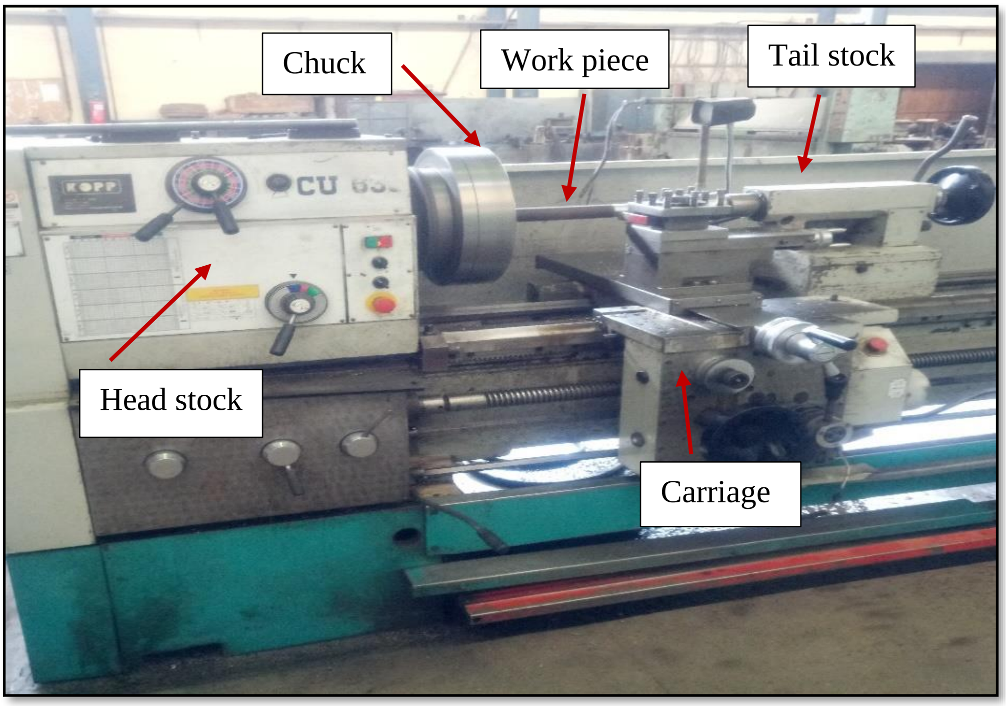

Figure 3.5. Conventional lathe machine

C. Surface roughness measuring device

Surface roughness tester is an instrument used to measure a surface's profile, in order to quantify its roughness. There are different types of surface roughness tester, and a contact type profilometer is used to measure the surface roughness of the workpiece on this study. In this experimental work, the surface roughness values were measured using VOGEL roughness tester. By using this roughness measuring device three tests were done for each of nine experiments and the average value of roughness value was taken.

Figure 3.6. VOGEL surface roughness tester

D. Temperature measuring device

A temperature sensing device is used to measure the temperature of the cutting tool.

Figure 3.7. TROTEC BP21 Infrared thermometer; a) Side view and b) Front view

In this study, a TROTEC BP21 Infrared thermometer (often referred to as laser pyrometers) was used to measure the temperature generated at the tip of the cutting tool during the turning operation. This thermometer is widely used in industries to measure the temperature of kilns, gas turbine exhaust, diesel engines, and other industrial processes. TROTEC BP21 Infrared thermometer can measure a temperature value range from -35 °C to +800 °C.

E. Weight measuring device

In doing of this experimental work weight measuring devices are used to measure the mass of cutting tool before and after machining operation to calculate the volume of tool worn at the tip of the tool. A digital balance machine is used to measure the mass of the cutting tool for each run.

E. Optical microscopy

Image of flank wear for selected experimental runs are observed using an optical microscopy (Model- Huvitz HR – 300 series) exists in Material Engineering lab of Adama Science and Technology University.

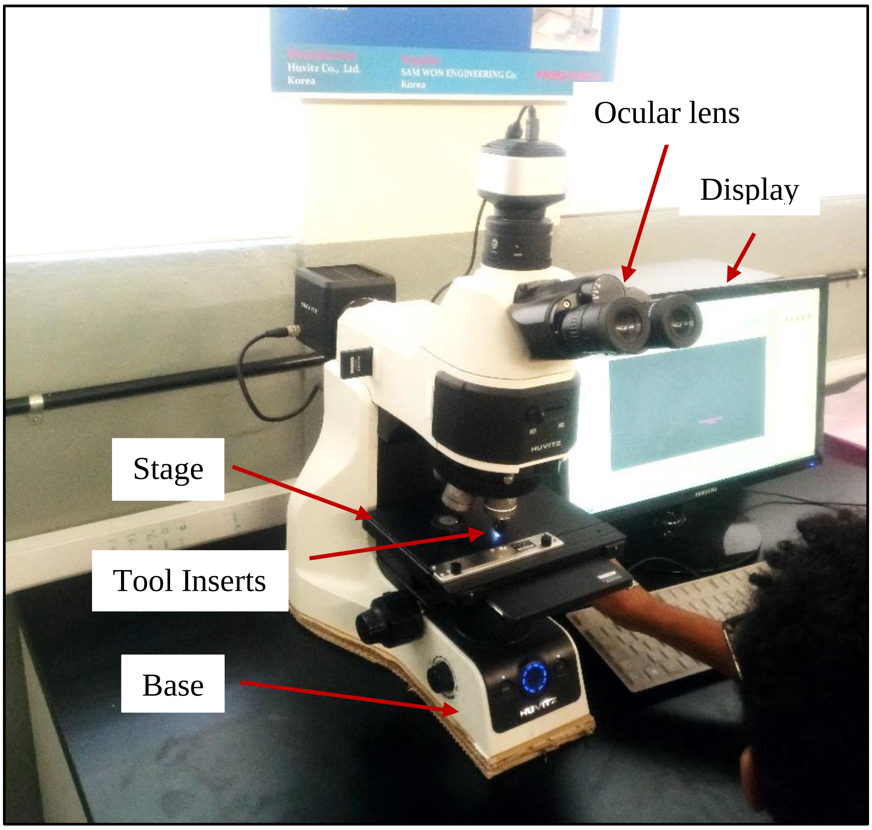

Figure 3.8. Optical microscopy

3.2. Methodology

3.2.1 Steps followed to do the experimental study

General steps followed during this experimental work is shown as Fig. 3.9

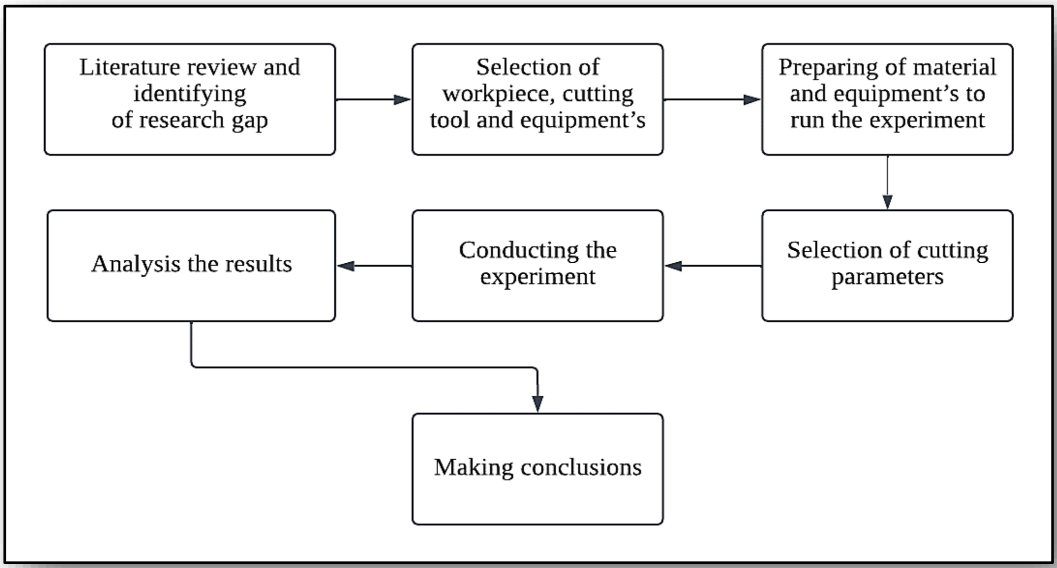

Figure 3.9. Flow chart of general steps followed during the experimental work

3.2.2. Optimization technique

The turning tests of selected workpiece (AISI 1026 steel) were conducted with the help of the DOE. DOE is an effective tactic to enhance the parameters in different manufacturing related process, and one of the best intelligent tools for optimization and analyzing the effect of input parameters on the end response. DOE introduces the method of planning tests so that suitable information can be analyzed utilizing statistical methods which result in substantial and objective conclusions (Hossein and Kops, 2017). There are different optimization techniques and the following are the most common DOE techniques:

a) Factorial Designs

b) One Factor Designs

c) Response Surface Method Designs

d) Taguchi's Orthogonal Arrays

e) Mixture Designs etc.

From all these, the selected one is Taguchi's orthogonal arrays. Taguchi's orthogonal array is used to estimate main effects using few experimental runs. Taguchi optimization technique has advantages in which it requires minimum number of experiments, shorter period of time and minimum cost to conduct the experiment. In Taguchi methods, the word optimization means determination of best levels for the control factors that minimizes the effect of noise. The best levels of control factors are those that maximize the SNR.

General steps in doing Taguchi method are shown in Fig. 3.10.

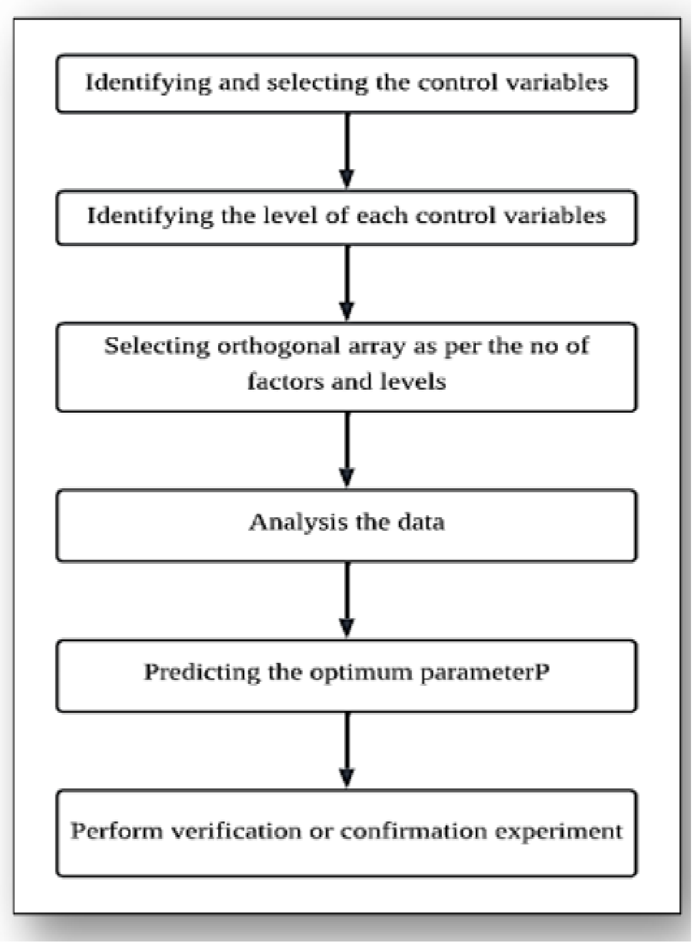

Figure 3.10. General steps in doing Taguchi method

By assessing the trial data and determining the ideal situations for a process, the Taguchi method estimates the percent of contribution of each factor and predicts the responses to the optimal conditions. For this experimental work L9 Taguchi orthogonal array was designed to do the experiment. In doing this experiment new edge of cutting tool insert was utilized for each (nine) experiments and the mean values of the response variables (surface roughness, material removal rate, tool wear rate) are calculated for each run.

3.2.3. Selection of cutting parameters and response variables

Selecting cutting parameters is one of the main tasks in doing this experimental work. The cutting parameters selected to do this research are speed of cut, depth of cut and feed rate, with three levels for each, while the response variables are surface roughness, material removal rate, tool tip temperature, machining time and tool wear rate. The levels of selected cutting parameters are chosen from the knowledge of previous literature and recommendations of workpiece and tool manufacturers as well as from industrial practices.

Table 3.4. List of selected parameters and levels

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/ rev)
1	500	0.2	0.05
2	800	0.6	0.1
3	1100	1	0.15

3.2.4. Selection of orthogonal array

The number of levels of various parameters were used to determine which orthogonal array to use. According to (Krishnaiah and Shahabudeen, 2012), the number of experiments required to investigate the factors must be more than the total degrees of freedom available.

Generally, the steps shown on Fig. 3.11 should be passed in selection of the right orthogonal array

Steps

1: Determine the degree of freedom required for the problem under study

2: Note the levels of each factor and decide the type of OA.

3: Select the particular OA which satisfies the following conditions.

- Degrees of freedom of OA > degree of freedom required for the experiment
- Possible number of interactions of OA > the number of interactions to be studied.

Figure 3.11. Main steps followed for designing an OA experiment

On this study three factors with each three levels are selected as shown on Table (3.5). The required degree of freedom is calculated by equation 3.1 (Krishnaiah and Shahabudeen 2012).

$$DOF = P * (L - 1) \tag{3.1}$$

Where; DOF: degrees of freedom; P: number of factors; (3 for this study); L: no of levels, (3 for this study).

Inserting respective values in to the equation 3.1 and calculating it DOF is found six. Total number of experiments of orthogonal array (OA) should be larger than or equal to total DOF required for testing, due to this L9 orthogonal array was preferred to make the experiments.

3.2.5. Design matrix

In the present work three factors (spindle speed, depth of cut and feed rate) with three levels for each are selected and Taguchi L9 orthogonal array was chosen. As a result of this the variables are formed according to Taguchi L9 array design with the help of MINITAB18. The design matrix of variables is shown in the Table 3.5.

Table 3.5. Design matrix of variables

Exp. No.	Spindle speed (rpm)	Depth of cut (mm)	Feed (mm/rev)
1	500	0.2	0.05
2	500	0.6	0.1
3	500	1	0.15
4	800	0.2	0.1
5	800	0.6	0.15
6	800	1	0.05
7	1100	0.2	0.15
8	1100	0.6	0.05
9	1100	1	0.1

3.2.6. Signal to noise ratio

To consider the variation of results, Taguchi method uses the SNR to identify the quality characteristics applied in engineering design problems. In machining of a workpiece cutting parameters that affect the required end responses are classified in to controllable (signal) and uncontrollable (noise) factors (Moganapriya *et al.*, 2018). The quality characteristic device from the desired value is measured by SNR and often expressed in decibels. There are three cases regarding signal to noise ratio, nominal the better, smaller the better and larger the better. In this study smaller the better SNR is used for the analysis of surface roughness, whereas larger the better is used for the analysis of material removal rate. Signal to noise ratio for nominal the better, smaller the better and larger the better condition is described as equations 3.2, 3.3 and 3.4 respectively.

$$\frac{S}{N} = 10\log\left(\frac{y^2}{s^2}\right) \tag{3.2}$$

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right) \tag{3.3}$$

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{{y_i}^2}\right) \tag{3.4}$$

Where, y = observation; n = total number of observations, s^2 =the variation of y and y_i = i^{th} response.

The SNR was calculated for surface roughness and material removal rate in each of the nine trial conditions to see the impact of each parameter on the reaction in dry turning of selected workpiece.

3.2.7. Analysis of variance

In this work finding of the main significant factors that affect the end responses are one of the major tasks. To identify the significant parameters ANOVA was utilized. ANOVA is a statistical technique used to find the influence of control parameters and to identify the significant factors. In this technique the percentage contribution of each factor was used to measure the corresponding effect on the end responses.

3.2.8. Measurement of surface roughness

Surface roughness is calculated measuring the average of surface heights and depths across the surface of the worked part. Roughness is a good pointer of the potential functioning of a mechanical element, since irregularities on the surface may form nucleation sites for cracks or corrosion. Surface roughness can be defined in a variety of ways depending on the application, but average roughness (Ra) is the most common (Kumar *et al*., 2014). Average surface roughness is typically measured in microns (μm). In this experimental work, the surface roughness parameters were measured using VOGEL roughness tester. By using this roughness measuring device three tests were done for each of nine experiments and the average value of roughness value was taken.

3.2.9. Material removal rate

Material removal rate is expressed as the volume of material removed per unit time and its one factor that shows productivity of a machining industry in roughing operation and production of large batches. There are different methods to calculate the volume of material removed per unit time and two of them are shown on equations 3.5 and 3.6.

For the sake of this work MRR is calculated from the multiplication of feed rate, spindle speed, and change in diameter of workpiece as equation 3.6 (Bhavani *et al.*, 2017).

$$\text{MRR} = v_c * f * a_p \tag{3.5}$$

$$\text{MRR} = \pi/4 \, (D^2 - d^2) * f * N \tag{3.6}$$

Where,

MRR: material removal rate

v_c: cutting speed (m/min),

f: feed (mm/rev),

a_p: depth of cut (mm)

D: initial diameter of workpiece (mm)

d: final diameter of workpiece (mm)

N: spindle speed (rpm)

3.2.10. Measurement of tool tip temperature

The temperature developed while machining operation takes place plays a vital role in tool wear which consequences in poor surface finish and changes the properties of the work part and tool materials (Chikalthankar *et al*., 2014). As a result of this maintaining of temperature to the lowest value is the crucial thing in machining operation. In this study infrared thermometer is used to measure the temperature occurred at tip of cutting tool on each run during the turning of the work-piece from initial to the end of operation and the average value is taken.

3.2.11. Chip morphology

Chip morphology is the outcome of specific chip formation mechanism taking place during machining. Chip morphology contains an information regarding the cutting mechanism and machinability of a work part. Different types of chip morphologies can be seen during machining of a metal. Classification of chips are generally divided into three groups; discontinuous chips; continuous chips and chips with built-up-edges (Awopetu and Ayodeji, 2008). The type of material, type of cutting tool and cutting conditions, cutting parameters, can affect the formation of chips. In this experimental study types of chips formed was identified.

3.2.12. Measurement of machining time

Machining time is the time a machine is really processing anything. Generally, the term machining time is commonly employed when there is a removal of undesired material from the workpiece. Time taken for each experimental run was recorded using a stop watch.

3.2.13. Measurement of tool wear rate

In metal cutting operations, the wear of tools is generated largely due to the heat emitted from the cutting zone. Because of environmental concerns, Engineers try to avoid using cutting coolants and perform cutting operations in almost dry conditions (Abou and Kops, 2017). Productivity of machining industries is limited by tool wear which indirectly denotes a significant portion of the machining costs. However, selecting the optimal cutting parameters and cutting tool material with suitable cutting conditions an acceptable rate of tool wear may be attained and results in lowering the total machining cost (Patwari *et al.*, 2012). In this study tool wear rate was calculated using weight of cutting tool before and after experiment and substituting it in to tool wear rate formula as discussed in next chapter.

CHAPTER-4

RESULTS AND DISCUSSION

4.1. Introduction

In this study, experimental work was carried out by taking different combinations of input parameters (depth of cut, speed, and feed rate) to analyze the end responses like surface roughness, material removal rate, tool tip temperature, machining time, and tool wear rate. The experiment was carried out on a conventional lathe machine using a carbide insert cutting tool. Nine experiments were performed to identify the optimum condition. During and after the machining operation, measurements were taken for each of the end responses and statistical analysis was made to get the optimum parameters according to the requirement, and the main effects are identified. The values of responses that are conducted by orthogonal array are analyzed using Taguchi optimization technique. Statistical work was performed using Minitab 18 software.

4.2. General view of the samples after experiment

First, before the experiment, the workpiece was taken to a conventional lathe machine and its diameter was minimized to 35 mm from 40 mm (diameter of the prepared workpiece) to get a clean surface. After this, the sample was further minimized to a diameter of 33.5 mm at a difference of 39 mm length from the right side to the left for 1mm at nine places. This is done to separate and easily identify the experiment numbers due to the groove produced by doing so. The first three experiments are done at same spindle speed, i.e., 500 rpm, with different feed rates (0.05, 0.1 and 0.15 mm/rev) and depth of cut (0.2, 0.6 and 1mm). In the same way, experiments numbers 4, 5 and 6 are also carried out at same spindle speed i.e., 800 rpm, with different feed rate (0.1, 0.15 and 0.05 mm/ rev) and depth of cut (0.2, 0.6 and 1 mm). Also experiments numbers 7, 8 and 9 are performed by taking a spindle speed of 1100 rpm, with different feed rates (0.15, 0.05 and 0.1 mm/ rev) and depth of cuts (0.2, 0.6 and 1 mm). Table 4.1 shows the process route sheet for turning AISI 1026 steel.

Table 4.1. Process route sheet of turning operation

Step No.	Description of operation	Machine used	Tool used
05	Cut off the blank Ø40, length 410 mm	Hack Saw	Hack Saw
10	Face at the right side of the workpiece	Lathe machine	Carbide cutting tool
15	Make a center at right end side	Lathe machine	Center drill Ø5mm, with 60^0
20	Clamp the work piece on the lathes chuck and support with tailstock center, and turn from Ø40mm to Ø35mm, length 380mm from right end to left.	Lathe machine	Carbide cutting tool
25	Turn from Ø35mm to Ø33.5mm, length 39 to 40mm, 79to 80mm, 119 to 120mm, 159 to 160mm, 199 to 200mm, 239 to 240mm, 279 to 280mm, 319 to 320 mm, 359 to 360mm from the right end to the left to make small grooves to separate the experiment numbers.	Lathe machine	Carbide cutting tool
30	Adjust the cutting parameters (spindle speed, depth of cut and feed rate) on the lathe according to designed experiment and turn each of the nine experiments.	Lathe machine	Carbide inserts cutting tool
35	At the end check the diameter of the machined surface weather its correct or not.	Vernier caliper	

The required results are measured during the turning operation and after the operation. In this study, the online measurement taken was the result of tool tip temperature, measured while doing the turning operation using a temperature measuring device (TROTEC BP21 Infrared thermometer), and machining time. Other measurements are taken after the turning operation and some of them are surface roughness, material removal rate, tool wear rate.

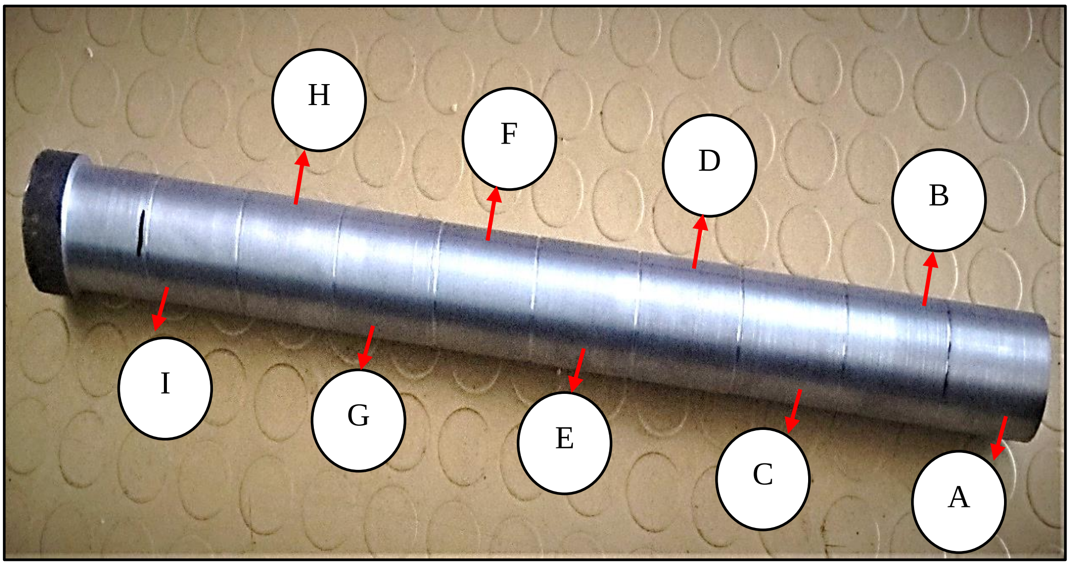

Figure 4.1. Sample after turning operation

4.3. Experimental result of surface roughness

As indicated in Table 4.1, average surface roughness values (Ra) and SNR were obtained in turning of AISI 1026 steel in dry turning condition employing carbide cutting tools using L9 orthogonal array of the Taguchi experimental design method with three levels of spindle speeds, depth of cut, and feed rates for each. For each experimental run three measurements of surface roughness were taken and an average value of the result was analyzed. Using Minitab18, SNR were determined according to Taguchi's "the smaller, the better" quality characteristics.

Fig. 4.2. shows the value of average surface roughness for each experimental run. The highest average surface roughness value (2.787 µm) occurred at experiment number three, and the lowest average surface roughness value (1.243 µm) was obtained at experiment number eight, as shown in the figure. The remaining experiment's average surface roughness values fall somewhere between these two extremes.

Table 4.2. Experimental result of surface roughness.

Exp. no.	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Surface roughness (μm)			Avg. Ra (μm)	SNR
				Meas.1	Meas.2	Meas.3		
1	500	0.2	0.05	1.87	1.8	1.83	1.833	-5.26325
2	500	0.6	0.1	2.16	2.05	2.11	2.107	-6.47329
3	500	1	0.15	2.86	2.89	2.61	2.787	-8.90274
4	800	0.2	0.1	1.7	1.75	1.72	1.723	-4.72571
5	800	0.6	0.15	1.99	2.01	2.39	2.130	-6.56759
6	800	1	0.05	1.9	1.64	1.56	1.700	-4.60898
7	1100	0.2	0.15	1.66	1.5	1.37	1.510	-3.57954
8	1100	0.6	0.05	1.25	1.25	1.23	1.243	-1.88942
9	1100	1	0.1	1.37	1.38	1.41	1.387	-2.84153

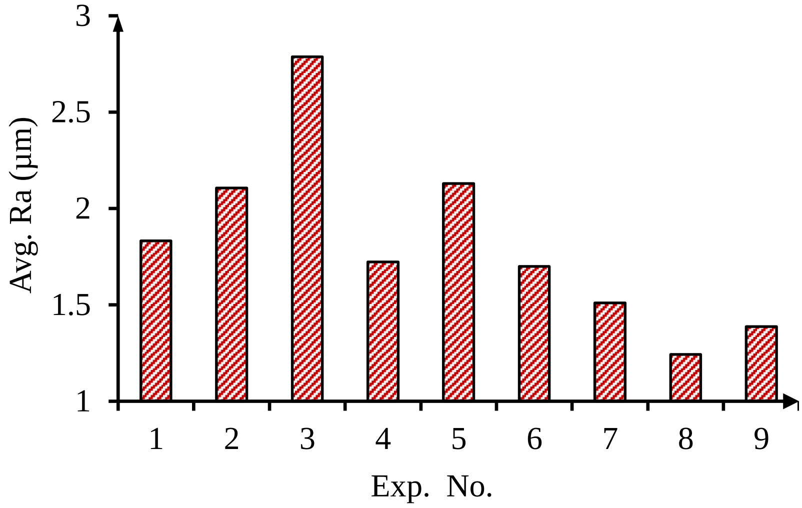

Figure 4.2. Average surface roughness value at different experiments

4.3.1. Response table for mean

The response table can show which factors have the most impact on the response and to what degree of the factor is associated to greater or lower response characteristic values.

Steps to generate a response table

a) The first step is to Calculate the selected response characteristic for each level of cutting speed, feed rate and depth of cut.

b) The difference between the highest average response characteristic value and the lowest average response characteristic value for each level of that factor is then calculated as delta values.

c) The delta values are used to assign ranks ranging from high to low. The factor with the highest delta value receives the top ranking.

Table 4.3. Response Table for Means

Level	Spindle speed	Depth of cut	Feed rate
1	2.242	**1.689**	**1.592**
2	1.851	1.827	1.739
3	**1.380**	1.958	2.142
Delta	0.862	0.269	0.550
Rank	1	3	2

Taguchi response for the mean effect of components on surface roughness for smaller is better features is shown in Table 4.3. The table shows that from the three parameters, spindle speed has the highest impact on surface roughness (Delta = 0.862, Rank = 1), while depth of cut has the least impact (Delta = 0.269, Rank = 3). This mean response table was utilized to fine-tune the settings for a better outcome. As shown in the table, a higher level of spindle speed (1100 rpm) and lower values of both depth of cut and feed rate (0.2mm and 0.05mm/rev respectively) was a viable combination for improving surface roughness.

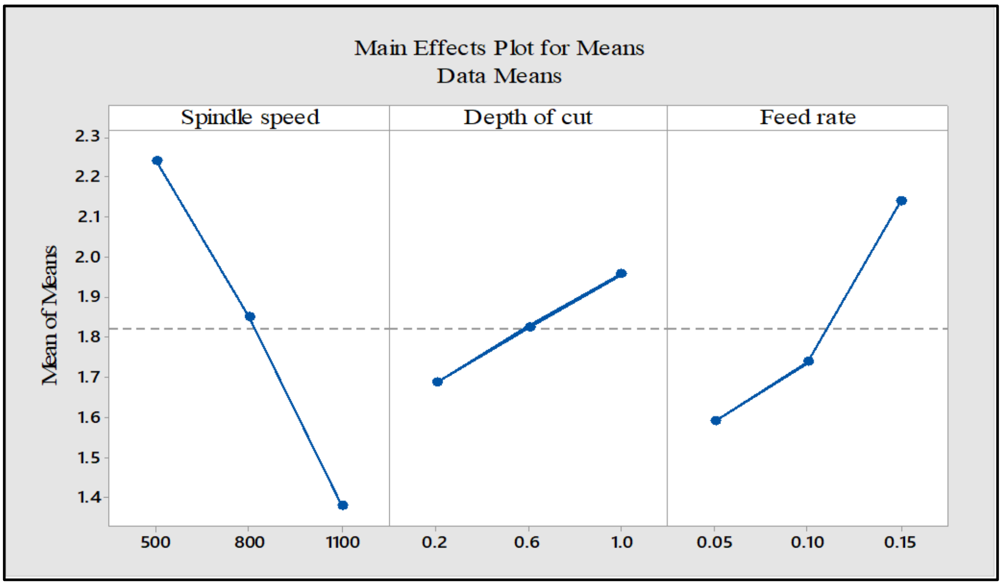

Figure 4.3. Main effect plots for mean

Taguchi result of the main effect plot for means is shown in Fig. 4.3. The optimum condition for better surface finish is occurred at the minimum point in the graph for each turning parameter. From the figure it can be concluded that minimum surface roughness attained when the spindle speed is at the highest level (1100 rpm) and both the feed rate and depth of cut are at the lowest level (0.2 mm and 0.05 mm/rev, respectively).

Low spindle speeds result in a greater built-up edge (BUE) and easily fragmented chips, resulting in a rough surface. To overcome this increasing the spindle speed is advantageous to remove the built-up edges, thus reducing chip fracture and resulting in a superior finish (Davis *et al*., 2012).

4.3.2. Interaction effect

An interaction effect is the simultaneous effect of two or more independent variables on at least one dependent variable in which their joint effect is significantly greater (or significantly less) than the sum of the parts. Interaction effects are crucial in any survey research because they tell researchers how two or more independent factors interact to influence the dependent variable. In this case, interaction effects denote the influence of a third variable on the connection between an independent and dependent variable (surface roughness).

Fig. 4.4 shows the effect of spindle speed on surface roughness at different feed rate and it can be seen that as spindle speed increases from the lowest level to the highest level, keeping feed rate constant for each level of spindle speed, the surface roughness value decreases. When the feed rate is at 0.05 mm/rev, increasing the spindle speed from 500 rpm to 800 rpm results in a decreasing of the surface roughness value from 1.833 to 1.723 µm and increasing the spindle speed from 800 to 1100 rpm the roughness value is decreased to 1.243 µm. When the feed is kept at 0.1 mm/rev and the spindle speed is increased from 500 to 800 and 1100 rpm, the roughness value decreases from 2.107 µm to 1.723 µm and then decreases to 1.387 µm. Surface roughness value is at 2.787 µm when the feed was 0.15 mm/rev and the speed was 500 rpm, but the roughness value decreases to 2.13 µm and 1.51 µm as the spindle speed increased to 800 rpm and 1100 rpm, respectively, keeping the feed at 0.15 mm/rev.

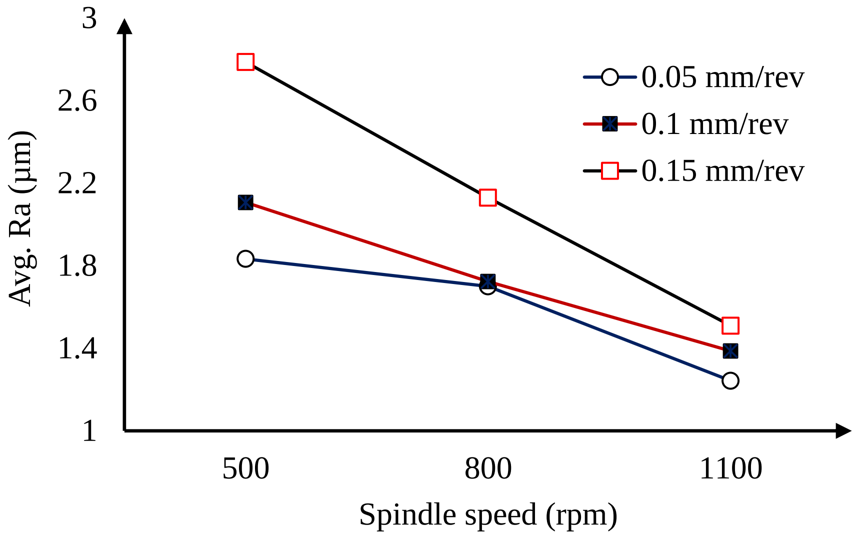

Figure 4. 4. Effect of spindle speed on surface roughness at different feed rate

The effect of spindle speed on surface roughness value at different level of depth of cut is shown in Fig. 4.5. The graph shows that the roughness value is initially 1.833 µm and then it is decreased to 1.7µm and further decreased to 1.51 µm when the speed is initially at 500 rpm and then increased to 800 rpm and further increased to 1100 rpm, keeping the depth of cut constant at 0.2 mm. Average Ra value increased from 2.107 to 2.13 µm and finally decreased to 1.243 µm as the spindle speed increases from 500 to 800 rpm then to 1100 rpm, keeping the depth of cut constant at 0.6 mm. In the same way, increasing the spindle speed and keeping the depth of cut constant at 1 mm, the average Ra value decreases from 2.787 µm to 1.7 µm and 1.387 µm.

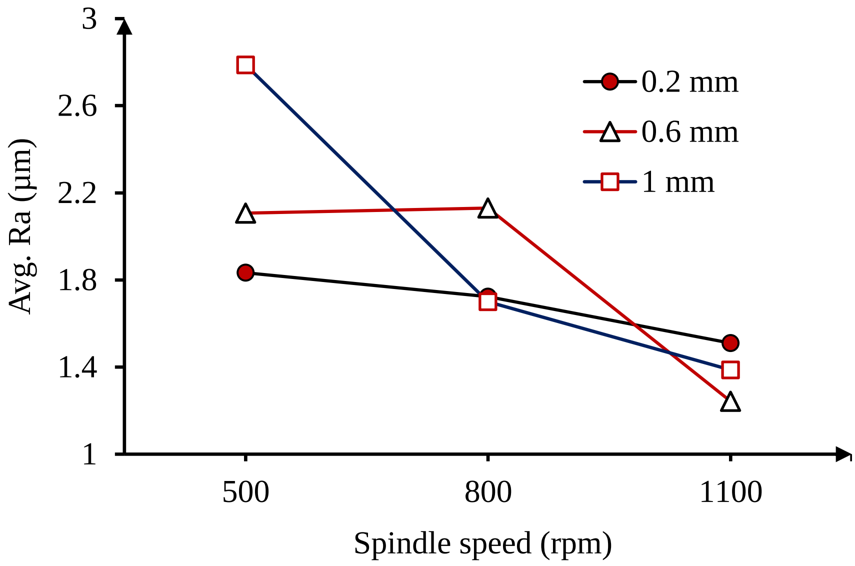

Figure 4.5. Effect of spindle speed on surface roughness at different level of depth of cut

From Fig. 4.6, it can be seen that increasing of the feed rate while keeping the spindle speed constant results in an increasing of roughness value. Keeping the spindle speed at 500 rpm and increasing the feed rate from the lowest level to the highest-level results in an increase in the average roughness value from 1.833 µm to 2.787 µm. Maintaining spindle speed at 800 rpm and increasing the feed rate results in an increase of the average roughness value from 1.7 µm to 2.13 µm. When the spindle speed is 1100 rpm and increasing the feed rate from 0.05 to 0.15 mm/rev results in increase of Ra from 1.243 µm to 1.51µm. This shows that increasing feed rate affects the average surface roughness value in dry turning of AISI 1026 steel, so to get the minimum surface roughness value it is recommended to select the minimum feed rate.

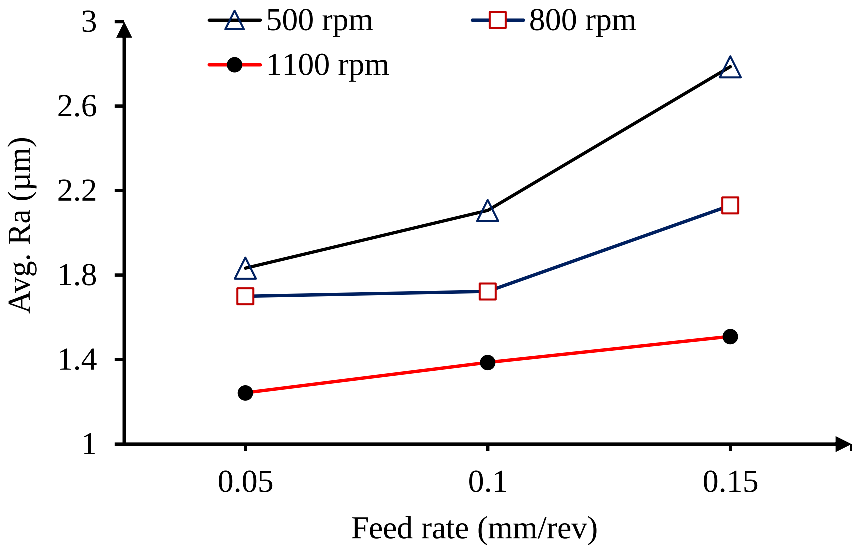

Figure 4.6. Effect of feed rate on surface roughness at different level of spindle speed

4.3.3. Response table for signal to noise ratio

Table 4.4. Response table for Signal to Noise ratios smaller the better

Level	Spindle speed	Depth of cut	Feed rate
1	-6.880	-4.523	-3.921
2	-5.301	-4.977	-4.680
3	-2.770	-5.451	-6.350
Delta	4.110	0.928	2.429
Rank	1	3	2

The spindle speed weight percentage has the biggest effect (Delta = 4.11, Rank = 1) when looking at the response table for signal to noise ratios in Table 4.4. Depth of cut has the least impact on SNR with Delta=0.928 and Rank 3).

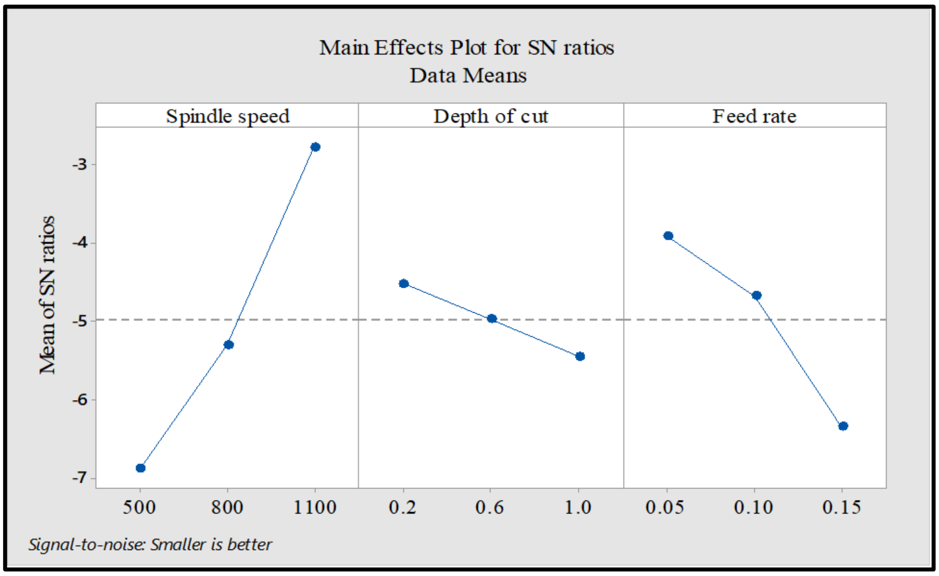

Figure 4.7. Main effects plot for SNR

The numerical value at the peak value for each graph represents the parameter's best value at that level. When compared to other cutting parameters, cutting speed is the most effective parameter that affects average surface roughness. Feed rate takes the second rank and depth of cut has the least effect on the value of average surface roughness.

Minimum surface roughness is obtained at a spindle speed of 1100rpm (highest level), 0.2 mm depth of cut (lowest level) and a feed rate of 0.05 mm/rev (lowest level). This combination is not existed on the orthogonal array designed on which the experiment was done. As a result of this a prediction of the surface roughness at this optimal parameter is required. The following linear regression equation is used to determine the predicted value of average surface roughness (Ebrahim *et al*., 2020).

$$y_{opt} = m + (mA - m) + (mB - m) + (mC - m) \quad (4.1)$$

Where, m = Average performance mean value for surface roughness,

mA = optimum level value for parameter A,

mB= optimum level value for parameter B,

mC= optimum level value for parameter C.

Regarding to this paper, mA represents the mean of surface roughness at the highest level of spindle speed (1100rpm), mB represents the mean of surface roughness at a lower level of depth of cut (0.2 mm), mC represents the mean of surface roughness at a lower level of feed rate (0.05 mm/rev) and m represents the average performance mean value for surface roughness (1.824 µm).

$$y_{opt}= 1.824 +(1.38 -1.824) + (1.689- 1.824) + (1.592- 1.824)$$

$$y_{opt} = 1.012 \ \mu m \text{ (Predicted optimum value of surface roughness)}$$

4.3.4. Confirmation test for predicted optimum results of surface roughness

The confirmation experiment in this study was designed to validate the optimal cutting conditions results for minimum surface roughness as predicted by Minitab 18 software. Levels of factors that are selected by Taguchi analysis as the optimal cutting parameters results for minimum surface roughness are used to conduct a verification experiment. Selected optimal cutting parameters by Taguchi analysis are: high level of cutting speed (1100 rpm), low level of depth of cut and feed rate (0.2 mm and 0.05 mm/rev respectively). Using these three cutting parameters, the predicted result is checked by the experiment. The experimental result of optimal level of cutting parameters and the comparison with the predicted value is shown in Table 4.5.

Table 4.5. Experimental result of surface roughness at optimal cutting parameters

Confirmation test	Surface Roughness Ra(µm)			Mean of Ra(µm)	Predicted Value of Ra (µm)	Error %
	Meas. 1	Meas. 2	Meas. 3			
	1.09	1.03	1.07	1.063	1.012	4.798

The difference between the experimental and predicted results is small and this shows that the experimental result is highly associated with the expected value.

4.3.5. Analysis of variance for surface roughness

ANOVA is a method of partitioning total variation into accountable sources of variation in an experiment. It is a statistical method used to interpret experimental data and make decisions about the parameters under study. Analysis of variance is used to identify the most significant parameters that affect the value of surface roughness in this case. ANOVA establishes the relative significance of factors in terms of their percentage contribution to the response. The level of significance was identified by the percent of contribution calculated by each factor. The significance level of 5%, i.e., for a 95 % level of confidence, was considered in this analysis. ANOVA involves when α values are below 0.05 are significant and above 0.05 is not significant. Percentage contribution of each influential parameter was calculated by the formula in equation 4.2. and Table 4.5 represents analysis of variance for surface roughness by using Minitab18 software.

$$P\ (\%) = \frac{SSTR - DoF * MSE}{SST} * 100 \quad (4.2)$$

Where, P: Percentage contribution of individual factor; DOF is degree of freedom; SST is total sum of squares; MSE is mean square error, and F is F- Ratio calculated using Minitab 18 software.

Table 4.6. Analysis of Variance

Source	DF	SST	MSE	F-Value	P-Value	Contribution %	Significance
Spindle speed	2	1.11860	0.55930	28.47	0.034	63.78%	Highly significant
Depth of cut	2	0.10883	0.05442	2.77	0.265	6.21%	Less significant
Feed rate	2	0.48715	0.24358	12.40	0.075	27.78%	Significant
Error	2	0.03929	0.01964			2.24%	
Total	8	1.75388				100.00%	

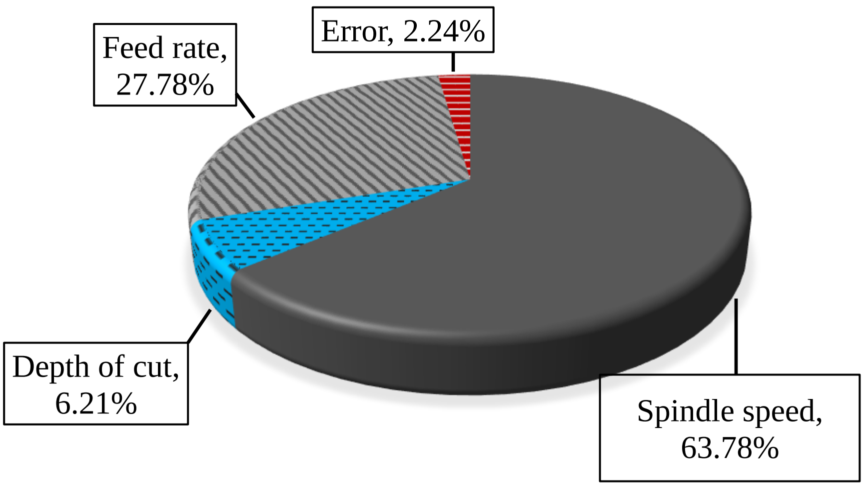

Figure 4.8. Contribution of cutting parameters on surface roughness value

From Fig. 4.8, it is observed that spindle speed has the highest contribution (63.78 %) followed by feed rate (27.78 %) and depth of cut (6.21 %) in affecting the value of average surface roughness during dry turning of AISI 1026 steel. Surface roughness is reduced by increasing spindle speed while decrease feed rate and depth of cut.

4.4. Analysis of material removal rate

The amount of excess material removed per unit time is called material removal rate. It is also defined as the volume of chip removed per minute when performing a machining operation like turning, milling, etc. Material removal rate is one of the measures of productivity in performing a machining operation. There are different techniques and formulas to measure the material removal rate and according to (Bhavani *et al.*, 2017) the formula on equation 4.3 was used.

$$MRR\ (mm^3/min) = \pi/4 * (D^2 - d^2) * f * N \quad (4.3)$$

Where; MRR- material removal rate; D- initial diameter of the workpiece (mm); d- final diameter of the workpiece after turning (mm); f – selected feed rate for the experimental run (mm / rev); N – selected spindle speed for the experimental run (rev/min).

For the sake of this paper, material removal rate was calculated using equation 4.3 and the result is displayed in Table 4.7.

Table 4.7. Calculated material removal rate

Exp. No.	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Calculated Material removal rate (mm^3/min)	SNR
1	500	0.2	0.05	546.637	54.7540
2	500	0.6	0.1	3242.123	70.2166
3	500	1	0.15	8011.061	78.0738
4	800	0.2	0.1	1749.238	64.8570
5	800	0.6	0.15	7781.096	77.8208
6	800	1	0.05	4272.566	72.6138
7	1100	0.2	0.15	3607.805	71.1449
8	1100	0.6	0.05	3566.335	71.0444
9	1100	1	0.1	11749.556	81.4004

Material removal rate is directly proportional to the three main cutting parameters (depth of cut, cutting speed and feed rate). From Table 4.7 it can be seen that the highest material removal rate was appeared at experiment number nine, which has a higher spindle speed, depth of cut and medium level of feed rate and minimum material removal rate is occurred on experiment number one, which is at the lowest value of spindle speed, feed rate and depth of cut. It is possible to say a machining industry is productive if the rate of material removal is higher, because it can produce a lot of products in a shorter period of time, but this is not always the case. Only high material removal rate does not mean economical machining, as economical machining requires good surface finish, less tool wear rate, and less power consumption, etc.

4.4.1. Analyses of mean

The average mean values of material removal rate for each individual factors i.e., spindle speed, depth of cut and feed rate was analyzed by using design of experiment. Minitab 18 software was used to calculate the mean of each individual factor and the result is presented in table 4.8.

Table 4.8. Response Table for Means

Level	Spindle speed	Depth of cut	Feed rate
1	3933	1968	2795
2	4601	4863	5580
3	**6308**	**8011**	**6467**
Delta	2375	6043	3671
Rank	3	**1**	2

From the Table 4.8 it can be seen that depth of cut is the most significant factor that affects the material removal rate (with Delta = 6043, rank = 1), followed by feed rate (with Delta = 3671, rank = 2) and spindle speed (with Delta = 2375, rank = 3). In analyzing of material removal rates the larger the better is selected and this condition is satisfied at spindle speed of 1100 rpm, depth of cut of 1mm, and feed rate of 0.15mm/rev. This shows that the highest material removal rate is occurred at higher spindle speed, higher depth of cut and higher feed rate.

Main effect plot for means of material removal rate

A main effect plot is a plot of the responses of mean values at each level of a design parameter or variable. Main effect plot can be used to compare the relative strength of effects of various factors. Main effect plot for means of material removal rate is shown on Fig 4.9.

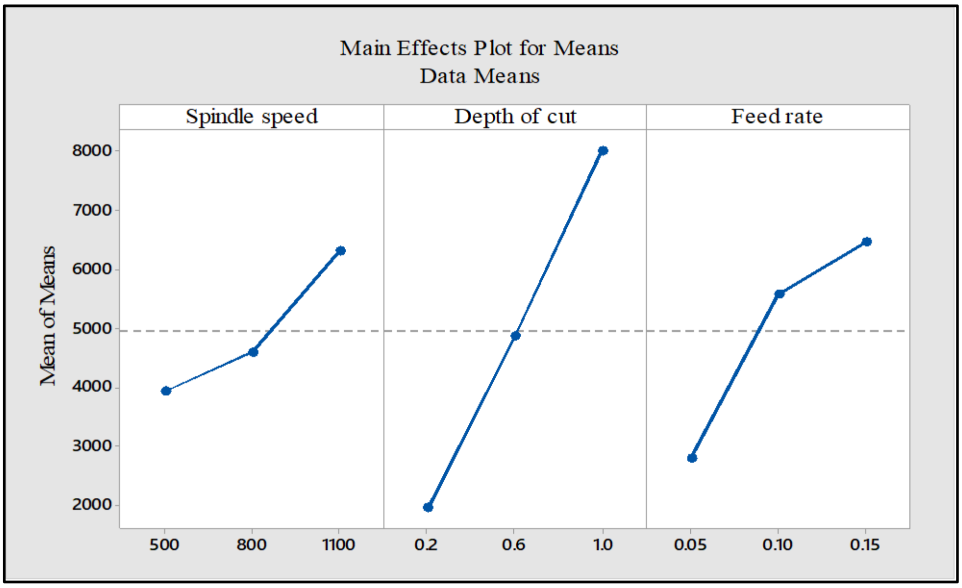

Figure 4.9. Main effects plot for means of material removal rate

From the scope of this topic the maximum point in the graph (highest level of spindle speed, depth of cut and feed rate) for each turning parameters are the optimum conditions at which better material removal rate is obtained.

4.4.2. Interaction effects

Fig 4.10. shows the effect of depth of cut on material removal rate at different cutting speeds. It is observed that at constant spindle speed of 500 rpm, increasing the depth of cut from 0.2 to 0.6 mm results in increasing of the material removal rate from 546.637 to 3242.123 mm^3/min and when depth of cut increases to 1mm material removal rate was increased to 8011.061 mm^3/min. At the same manner keeping the spindle speed constant at 800 rpm and increasing the depth of cut results in increasing of material removal rate from 1749.238 to 7781.096 mm^3/min (as the depth of cut increases from 0.2 to 0.6) and then the Material removal rate decrease to 4272.566 mm^3/min (as the depth of cut increases to 1mm). When the spindle speed is kept at 1100 rpm the result of material removal rate shows slightly decreasing when the depth of cut increases from 0.2 to 0.6 mm and MRR value increases incredibly as the depth of cut increases from 0.6 to 1 mm. The up and down result of MRR value is occurred due to the effect of feed rate on material removal rate.

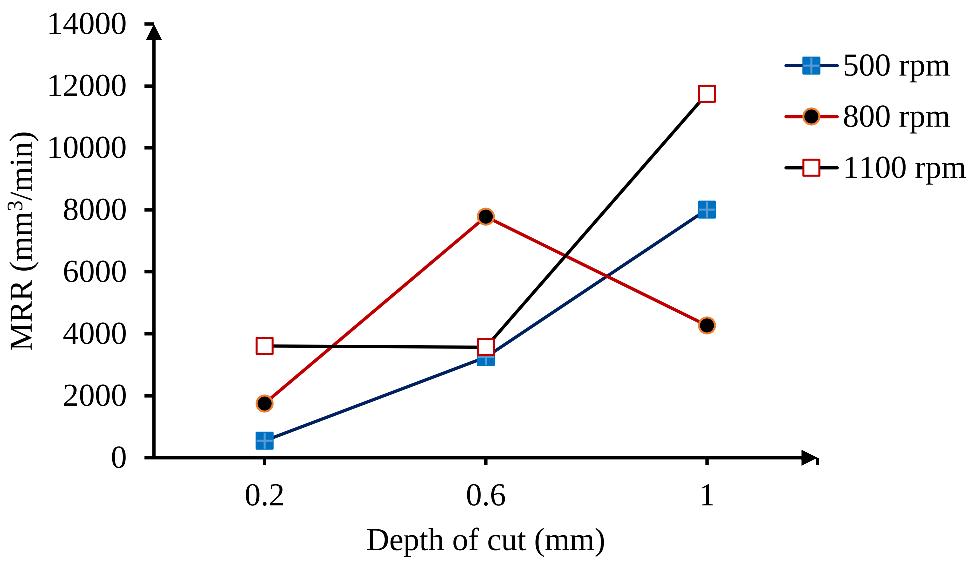

Figure 4.10. Effect of depth of cut on MRR at different spindle speed

Fig.4.11 below shows the effect of depth of cut at different feed rate. It describes the effect of increasing depth of cut on rate of material removed for each level of feed rate.

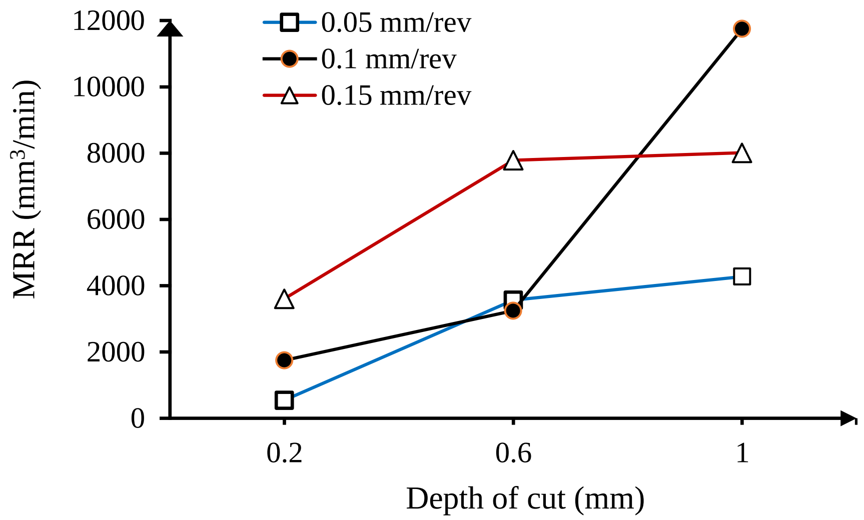

Figure 4.11. Effect of depth of cut on MRR at different feed rate.

Keeping the feed rate constant and increasing the depth of cut shows an in increase in MRR for each value of feed rate and this shows that depth of cut has significant effect on rate of material removal. Increase in MRR is not linear for some part of the graph and this is happened due to the additional effect of spindle speed on material removal rate.

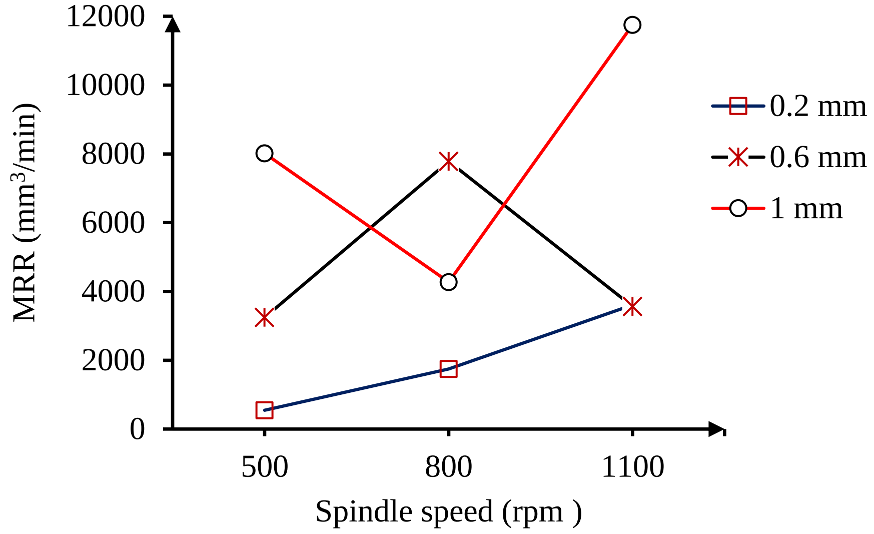

Figure 4.12. Effect of spindle speed on MRR at different depth of cut

Fig.4.12 shows the effect of spindle speed on MRR at different levels of depth of cut. Increasing of spindle speed from 500 to 1100 rpm keeping depth of cut on 0.2 mm results in increasing of MRR from 546.637 to 3566.335 mm^3/min. When the depth of cut is kept on 0.6 mm and spindle speed is increases from 500 to 800 rpm, the value of MRR reaches 7781.096 mm^3/min and when the spindle speed increases from 800 to 1100 rpm the value of MRR decreases significantly to 3566.335 mm^3/min. In other case when the depth of cut is remaining same at 1 mm and spindle speed increases from 500 to 800 rpm the MRR value is decreased from 8011.061 to 4272.566 mm^3/min and when the speed again increased from 800 to 1100 rpm MRR becomes 11749.556 mm^3/min.

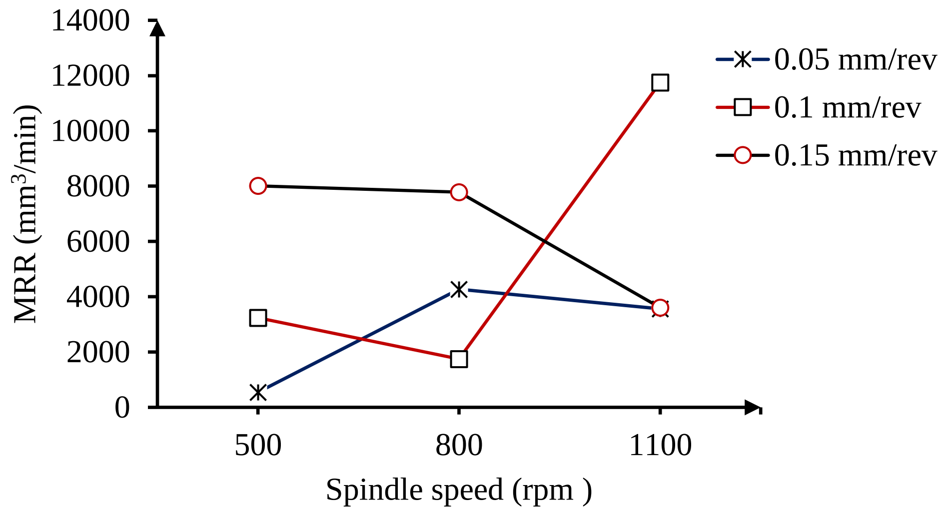

Figure 4.13. Effect of spindle speed on MRR at different feed rate

Fig.4.13 shows effect of spindle speed on MRR at different feed rate. When the feed rate is maintained at 0.05 mm/rev and spindle speed is increased from 500 to 800 rpm MRR value is increased to 4272.566 mm^3/min from 546.637 mm^3/min, and when the spindle speed is increased more the value of MRR is slightly decreased to 3607.805 mm^3/min. The MRR value is first decreased (from 3242.123 to 1749.238 mm^3/min) and then increased dramatically to 11749.556 mm^3/min when the spindle speed first increased from 500 to 800 rpm and then increased to 1100 rpm at constant feed rate of 0.1 mm/ rev. Volume of material removed is decreasing as the spindle speed increased and feed rate maintained at the highest level (0.15 mm/rev).

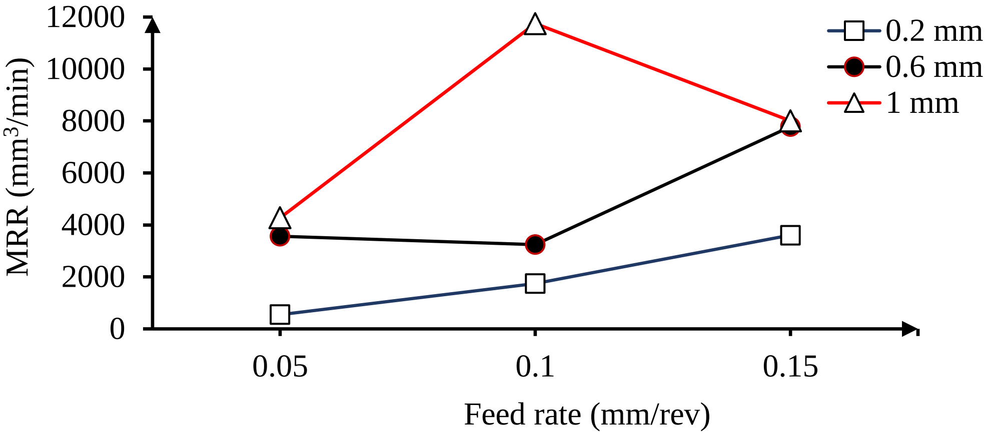

Figure 4. 14. Effect of feed rate on MRR at diferrent depth of cut

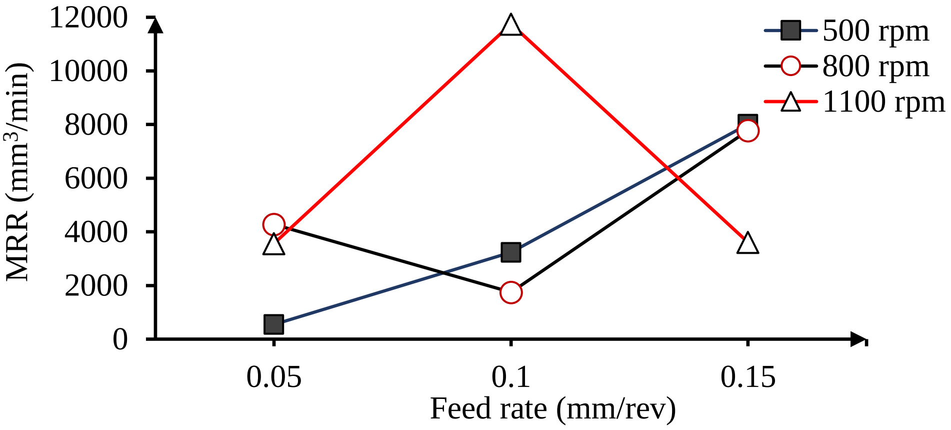

Figure 4.15. Effect of feed rate on MRR at diferrent spindle speed

Effect of feed rate on MRR at different depth of cut and spindle speed is shown on Fig. 4.14 and Fig 4.15 respectively. The results show that increasing of the feed rate from the lowest level to the highest results in increasing of the volume of material removed when the depth of cut is maintained at 0.2 mm, also MRR increases when spindle speed is remain the same at the lowest level (500) and feed rate increases. The volume of removed material slightly decreased from 3566.335 to 3242.123 mm^3/min when feed rate increases from the lowest to medium level and the volume of removed material increased from 3242.123 mm^3/min to 7781.096 mm^3/min when the feed upgraded to the highest-level keeping depth of cut constant at 0.6 mm. When the rpm is remain the same at 800 and feed rate increases from lowest to medium level MRR is decreased, and when feed rate increases again to the highest level MRR increases. Similar value of depth of cut at 1 mm and changing the feed rate from lowest level to highest level results in increasing of volume of material removed to midium level of feed rate and after that the value tends down. This result is the same when the spindle speed kept constant at 1100 rpm and increasing the feed rate to the highest level.

4.4.3. Analysis of signal to noise ratio

Signal to noise ratio is used to compare the level of desired signal to the level of background noise. Taguchi SNR, which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. In Taguchi method, response variation is studied with the help of SNR. Value of SNR of material removal rate for each run of the experiment was recorded in table 4.9.

The highest SNR is existing on experiment number nine, whose factors are valued with their highest level. Table 4.9. presents mean of signal to noise ratio for material removal rate where delta is the difference between maximum SNR and minimum SNR and Fig.4.16. shows Main effect plot for signal to noise ratio on material removal rate.

Table 4.9. Response Table for Signal to Noise Ratios

Level	Spindle speed	Depth of cut	Feed rate
1	67.68	63.59	66.14
2	71.76	73.03	72.16
3	74.53	77.36	75.68
Delta	6.85	13.78	9.54
Rank	3	**1**	2

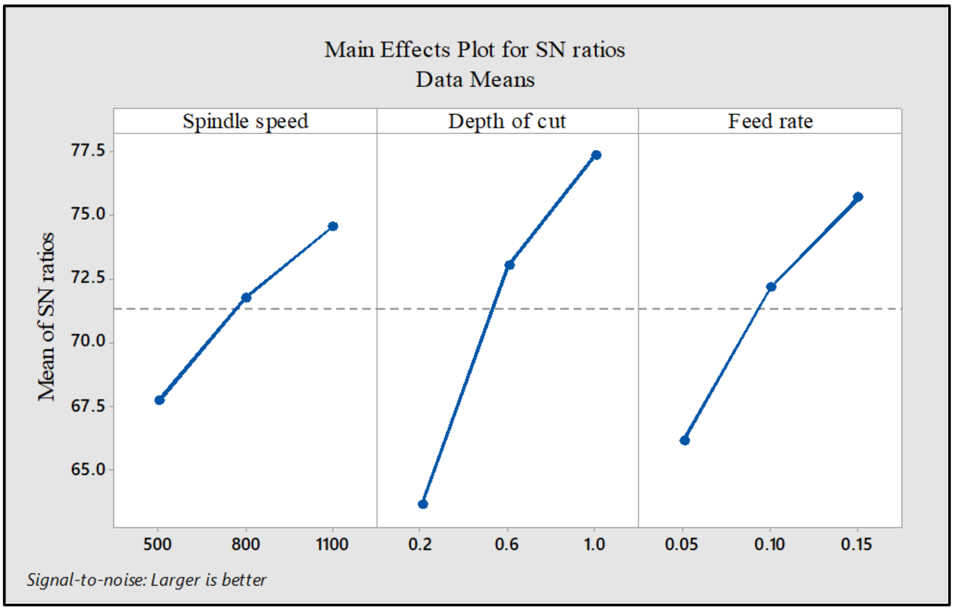

Figure 4.16. Main effect plot for signal to noise ratio

It can be clearly seen that, as the values of each parameter increases the signal to ratio increases, which shows that increasing of material removal rate. Also, from table 4.9 one can conclude that depth of cut weight percentage has the greatest effect (with delta 13.74 and rank 1), on volume of material removed followed by feed rate (with delta 74.46 and rank 2), and spindle speed (with delta 72.6 and ranked 3). From this result, it easy to say depth of cut had the most effective cutting parameter that affects the volume of material removed when compared to other cutting parameters (spindle speed and feed rate).

As it is discussed above higher MRR value is attained at higher level of all three factors i.e., 1100 rpm spindle speed, 1 mm depth of cut and 0.15 mm/rev feed rate. In the orthogonal array designed this combination were not exist and it is calculated after identifying the parameters which results in higher material removal rate. At this combination of levels of factors, material removal rate was found 17624.33 mm^3/min. However, getting highest material removal rate is not mean highly economical because of other factors like surface quality, and tool wear. So, for the sake of this paper material removal rate at optimum cutting parameters that gives smaller surface roughness is selected. MRR for optimum cutting parameters leads minimum surface roughness (at highest level of spindle speed 1100 rpm, and lowest levels of depth of cut 0.2 mm and feed rate 0.15 mm/rev) was calculated and its value is 4148.63 mm^3/min.

4.5. Analysis of tool tip temperature

Heat is developed while machining any type of material due to friction occurred between the cutting tool and workpiece. This heat generated while machining is best if it's too low since it affects the cutting tool as well as the work piece and also disturbs the operation. The undesirable temperature produced on cutting tool leads to rapid wear of cutting tool materials by softening of the tooltip. Many researches are done regarding to ways of minimizing the temperature produced during machining. One method of minimizing this temperature is selecting of suitable cutting tool and cutting parameters for the selected workpiece. In this experimental work the tool tip temperature generated at each run of the experiment was measured and the average temperature was taken and displayed in the table 4.10 below. The average temperature generated during turning of AISI 1026 steel varies with varying of cutting parameters as shown.

Table 4.10. Measured tool tip temperature

Experiment no.	Spindle speed (N) (rpm)	Depth of cut (t) (mm)	Feed rate (f) (mm/rev)	Average temperature (T_{ave}) (^oc)
1	500	0.2	0.05	36.4
2	500	0.6	0.1	38.6
3	500	1	0.15	42.3
4	800	0.2	0.1	43.8
5	800	0.6	0.15	47.4
6	800	1	0.05	43.0
7	1100	0.2	0.15	66.7
8	1100	0.6	0.05	59.3
9	1100	1	0.1	63.2

4.5.1. Analyses of mean

Using design of experiment, average mean values of average temperature generated on tool tip during dry turning of AISI 1026 steel for each individual factors i.e., spindle speed, depth of cut and feed rate was analyzed. Minitab 18 software was used to calculate the mean of each individual factor and the result is presented in table 4.11.

Table 4.11. Response Table for Means

Level	Cutting speed	Depth of cut	Feed rate
1	**39.10**	48.97	**46.23**
2	44.73	**48.43**	48.53
3	63.07	49.50	52.13
Delta	23.97	1.07	5.90
Rank	1	3	2

Average tool tip temperature produced in the turning operation was significantly affected by spindle speed (with delta of 23.97) than other factors as presented in table 4.11. Increasing spindle speed from lower to higher level results in significant increase of tool tip temperature. Feed rate takes the second rank with delta of 5.90 in affecting the tool tip temperature generated. Minimum average temperature is attained when spindle speed and feed rate are at their lowest level, and middle level of depth. This combination was not in OA designed, as a result of this it's predicted by Minitab18 software and it is found 35.8 ^{o}c.

Main effect plot for means tool tip temperature

A plot of responses of mean values at each level of a design parameter or variable is called a main effects plot. They used to compare the relative strength of the effects of various factors. The main plot effect for means of tool tip temperature is shown on Fig 4.17.

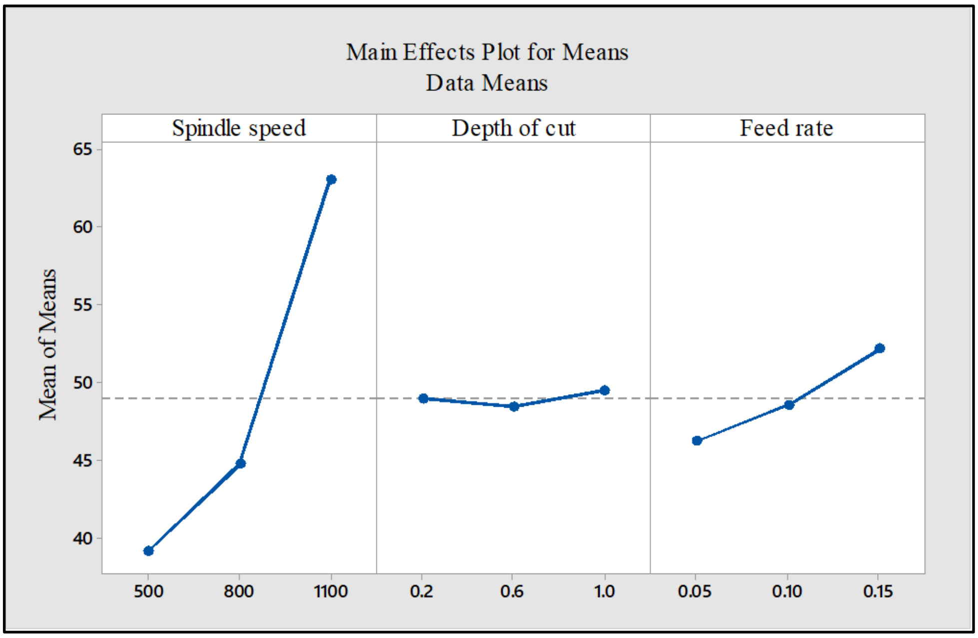

Figure 4.17. Main effect plot for means of tool tip temperature

The smaller values of temperature are preferred in this case and this temperature is attained at lower levels of spindle speed and feed rate, and at medium level of depth of cut. As it is seen from the figure as spindle speed increases the tool tip temperature is continuously raising. In addition to spindle speed, feed rate and depth of cut has also an effect on the tool tip temperature formed. It is simple to understand that the increasing of feed rate also results in increasing of temperature generated at the tool tip.

4.5.2. Interaction effects

Interaction effects of cutting parameters on tool tip temperature are presented in this section. At different feed rate increasing the spindle speed results in increasing of temperature at the tip of the cutting tool as shown on Fig 4.18. Keeping feed rate at 0.05 mm/rev and increasing spindle speed from 500 to 800 rpm results in increasing of tool tip temperature from 36.4 ^{o}c to 43 ^{o}c and it reaches 59.3 ^{o}c when spindle speed becomes 1100 rpm. When feed is 0.1 mm/rev average temperature was continuously increased from 38.6 ^{o}c to 43.8 ^{o}c and 63.2 ^{o}c as spindle speed increases from 500 rpm to 800 rpm and 1100 rpm respectively. increasing from. Maintaining feed rate at 0.15 mm/rev and increasing spindle speed results in increase of tool tip temperature from 42.3 ^{o}c to 66.7 ^{o}c. It can be concluded that increasing of feed rate and spindle speed results in increasing of temperature generated at the tool tip.

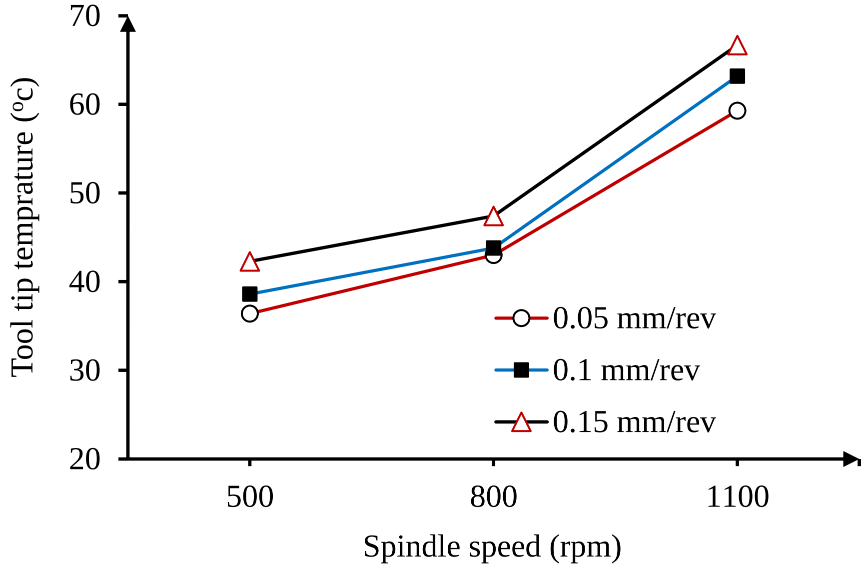

Figure 4.18. Effect of spindle speed on tool tip temperature at different feed rate.

Fig.4.19 shows effect of spindle speed on tool tip temperature at different depth of cuts. Tool tip generated was increased from 36.4 ^{o}c to 43 ^{o}c and reaches 66.7 ^{o}c when spindle speed increases from lower level to medium level and reaches higher level respectively keeping depth of cut at 0.2 mm. when depth of cut was at 0.6 mm and spindle speed increases from 500 to 1100 rpm, average tool tip temperature also increases from 38.6 ^{o}c to 59.3 ^{o}c. Maintaining depth of cut at 1 mm and increasing spindle speed from 500 rpm to 800 rpm results in increasing of tool tip temperature from 42.3 ^{o}c to 43 ^{o}c and reaches 63.2 ^{o}c. Generally, increasing the spindle speed from lower to higher level results in increasing of average temperature generated on the cutting tool tip at same level of depth of cuts.

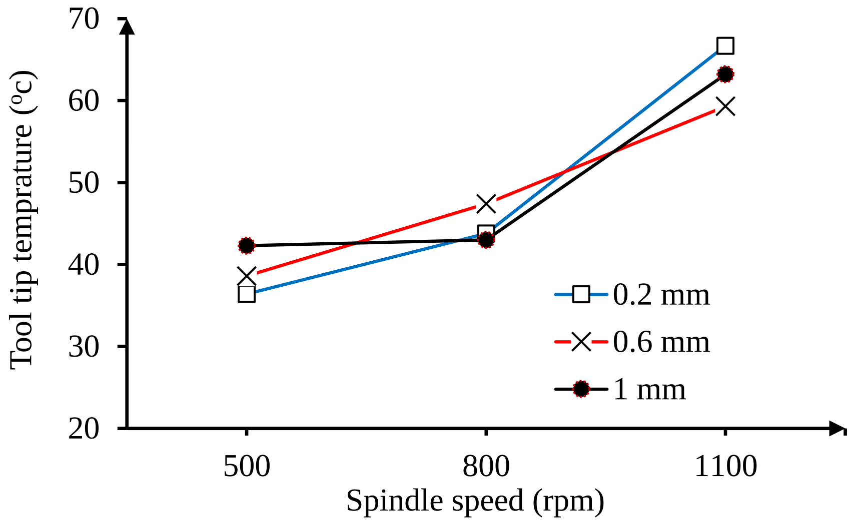

Figure 4. 19. Effect of spindle speed on tool tip temperature at different depth of cuts.

Fig. 4.20 shows the effect of feed rate on tool tip temperature at different levels of spindle speed. Keeping spindle speed at 500 rpm and increasing feed rate from 0.05 to 0.15 mm/rev result in increasing of tool tip temperature from 36.4 ^{o}c to 42.3 ^{o}c. in the same way maintaining spindle speed and increasing feed rate from lowest level to highest level result in increase of tool tip temperature from 43 ^{o}c to 47.4 ^{o}c. Tool tip temperature was first at 59.3 ^{o}c and increased to 63.2 ^{o}c and reaches 66.7 ^{o}c when depth of cut was at 1 mm and spindle speed increases sequentially between the levels. Generally, as feed rate increased and spindle speed maintained at the same level, the temperature is raised. The measured temperature is higher at higher levels of feed rate and spindle speed.

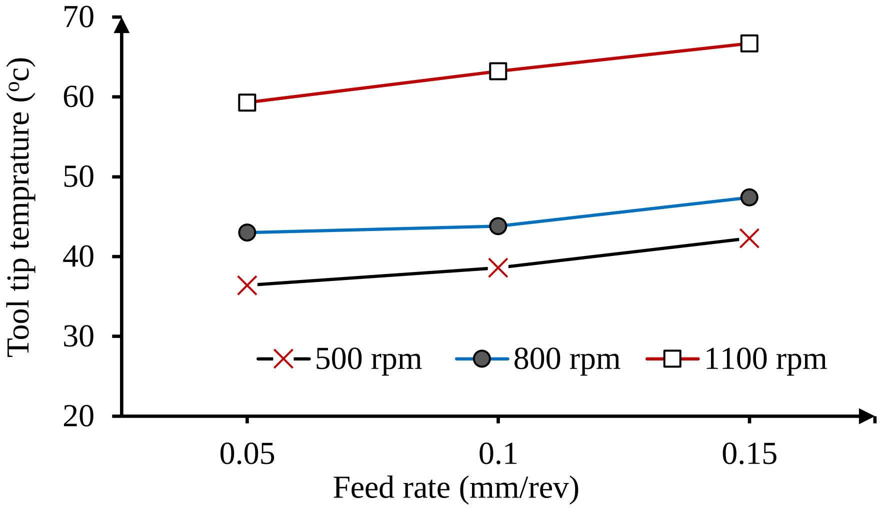

Figure 4. 20. Effect of feed rate on tool tip temperature at different spindle speed

Fig. 4.21 and 4.22 shows the contour plot of temperature vs spindle speed, depth of cut and Contour plot of tool tip temperature vs spindle speed and feed rate respectively.

Fig. 4.21 shows, tool tip temperature formed while turning of the selected metal increases as increasing of both spindle speed and feed rate. The temperature was < 40 ^{o}c when spindle speed was at lower level and up to medium level of depth of cut. When the spindle speed lies on medium level and higher level of depth of cut tool tip temperature comes between 40 to 45 ^{o}c. The temperature generated lies between 60 and 65 ^{o}c when spindle speed was at higher level (1100 rpm) and depth of cut was at lowest level and highest level.

From Fig. 4.22 it is observed that minimum average temperature (< 40 ^{o}c) was seen when spindle speed is around lowest level (500 rpm) and feed rate value up to middle level (0.05 to 0.1 mm/rev). When the spindle speed is on the middle level (800 rpm) and feed rate is at the higher level (0.15 mm/rev) the tool tip generated was lie between 40 to 45 ^{o}c. Higher value of tool tip generated was observed when both factors (spindle speed and feed rate) are at their highest levels.

Tool tip temperature is preferred if it is minimum and minimum average tool temperature was found on experiment number one. At this experiment number surface roughness value was higher, due to this average tool tip temperature at selected optimal surface roughness value was taken. Experimentally measured value of average tool tip temperature at optimal cutting parameters (1100 rpm, 0.2 mm and 0.05 mm/rev) was 58.3 ^{o}c.

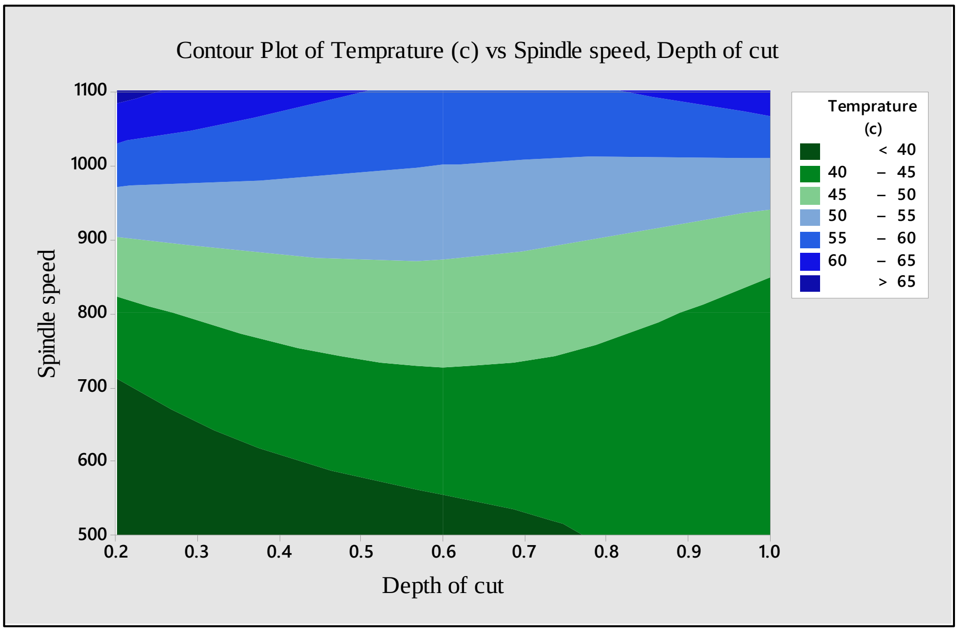

Figure 4.21. Contour plot of tool tip temperature vs spindle speed and depth of cut

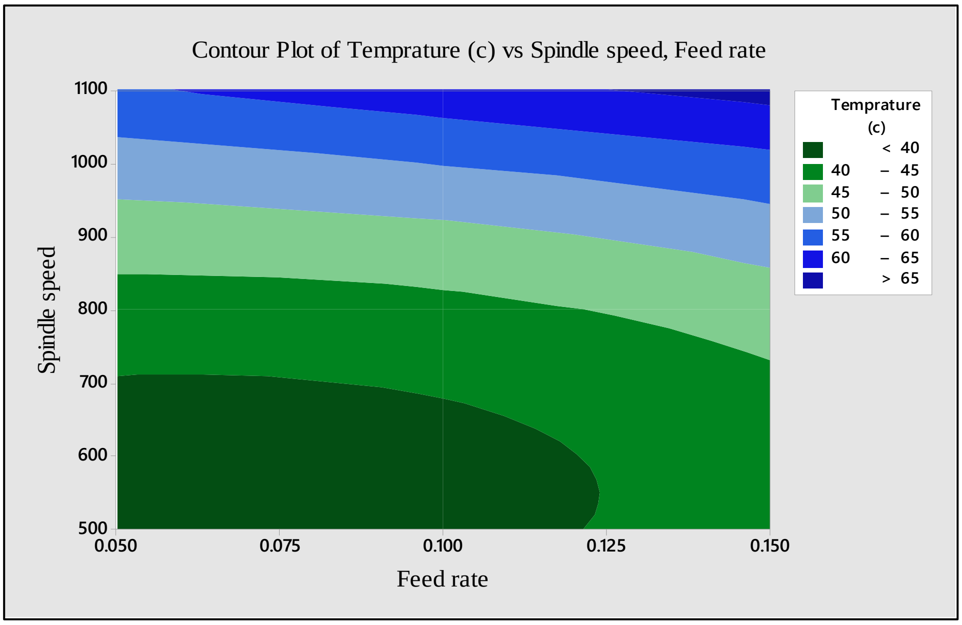

Figure 4.22. Contour plot of tool tip temperature vs spindle speed and feed rate

4.6. Types of chips formed in dry turning of AISI 1026 steel

Chip formation is a part of the process while turning operations are done. In doing this operation, different types of chips will be produced depending on the properties of the work piece, cutting tool selected, effect of cutting parameters, etc. Different researchers have been trying to investigate chip formation during machining of different materials.

Generally, types of chips formed are classified as shown in Fig. 4.23 (Iso,1993).

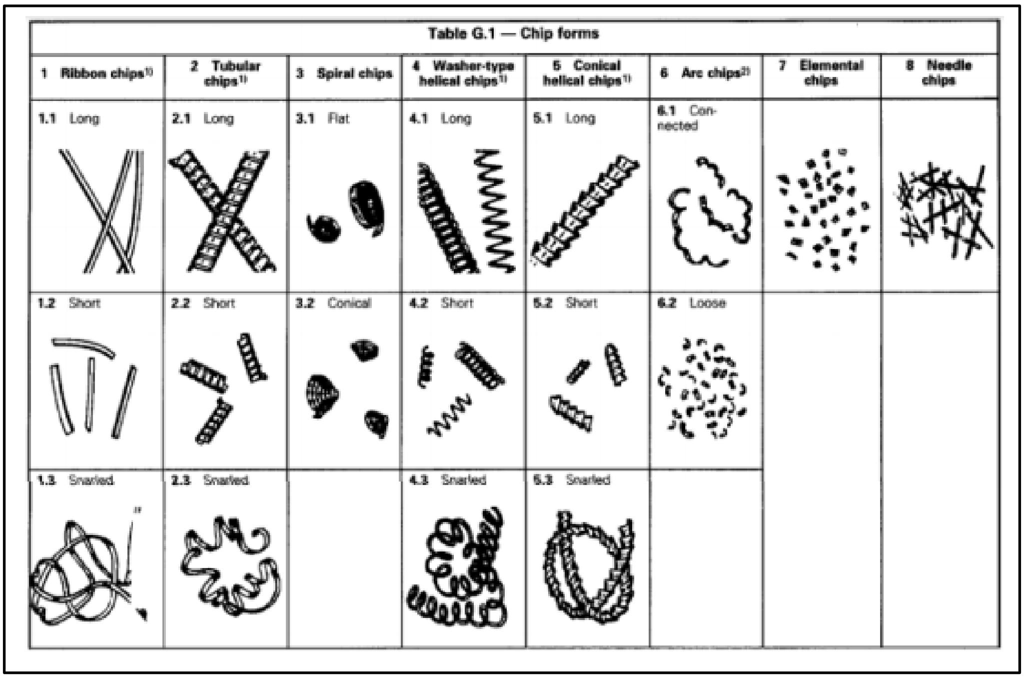

Figure 4. 23. Calcification of chips (Iso,1993)

In this section, type of chips formed while turning of AISI 1026 steel was described. While doing this experimental work, chip formed during the turning operation was collected for each of nine experiments. After collecting the chips, the type of chip formed was identified. Photographic pictures of chips formed during dry turning of AISI 1026 steel is shown in Fig. 4.24. As it is seen most of the chips formed are continuous chips. Type of chip formed is depend on property of selected workpiece, cutting tool and cutting parameters. Depend on Iso classification, types of chips formed are classified and in this experimental work snarled ribbon, snarled tabular and long washer type helical chips were observed. Long washer types of chips were observed on experiment number 3 and 6. Snarled ribbon chips were observed on experiment number 1,2,4 and 8. Snarled tubular types of chips were observed on experiment number 5,7 and 9.

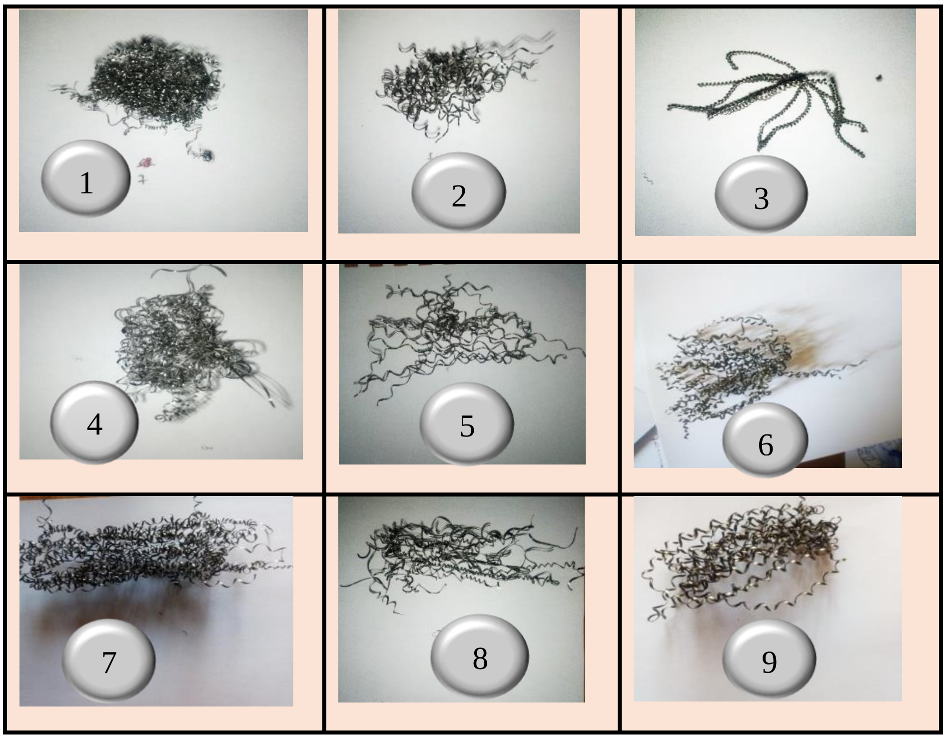

Figure 4.24. Chips generated during dry turning of AISI 1026 steel

4.7. Analysis of machining time

The time a machine is really processing anything is known as machining time. Generally, the term machining time is commonly employed when there is a removal of undesired material from the workpiece. Time taken for each run was recorded using a stop watch.

Table 4. 12. Measured time taken for each experimental run

Exp .No.	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Machining time (minute)
1	500	0.2	0.05	1.2
2	500	0.6	0.1	0.6
3	500	1	0.15	0.633
4	800	0.2	0.1	0.533
5	800	0.6	0.15	0.383
6	800	1	0.05	0.817
7	1100	0.2	0.15	0.267
8	1100	0.6	0.05	0.717
9	1100	1	0.1	0.433

In this section measured value of machining time for each of the experiment was analyzed. Fig.4.25 shows machining time for each experimental run.

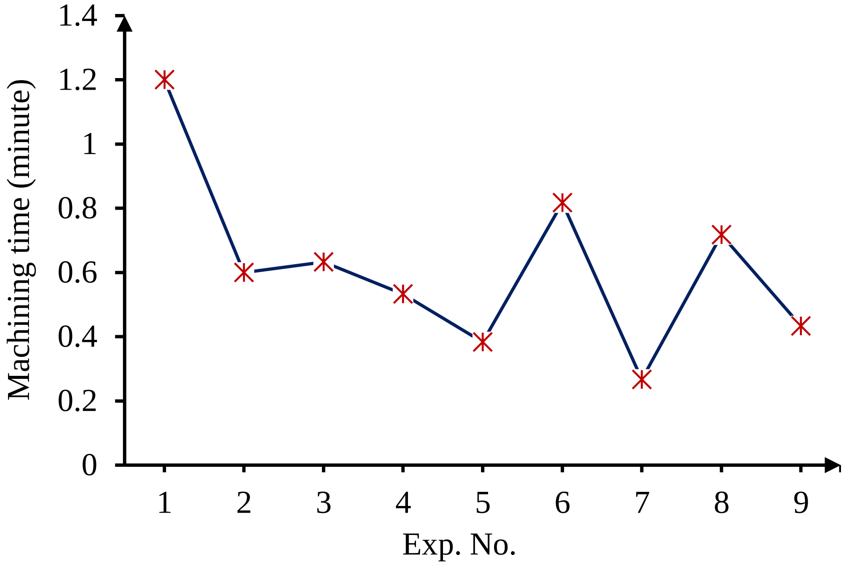

Figure 4.25 Machining time for each experimental run

Minimum cutting time was achieved at experiment number seven i.e., spindle speed of 1100 rpm, feed rate of 0.15 mm/rev and depth of cut of 0.2. Experiment number one (spindle speed of 500 rpm, feed rate of 0.05 mm/rev and depth of cut of 0.2) takes the highest time to complete the turning operation.

4.7.1. Analyses of mean

Table 4. 13. Response Table for Means

Level	Spindle speed	Depth of cut	Feed rate
1	0.8110	0.6667	0.9113
2	0.5777	**0.5667**	0.5220
3	**0.4723**	0.6277	**0.4277**
Delta	0.3387	0.1000	0.4837
Rank	2	3	1

Cutting time is mostly affected by feed rate followed by spindle speed as it is shown in table 4.13. Increasing of feed rate and spindle speed decreases the cutting time and, in the reverse, if the spindle speed and feed rate are in the lowest level the time required to complete turning operation is higher. From the response table it is seen that minimum machining time is attained at higher levels of spindle speed and feed rate and middle level of depth of cut (1100 rpm, 0.15 mm/rev and 0.6 mm respectively).

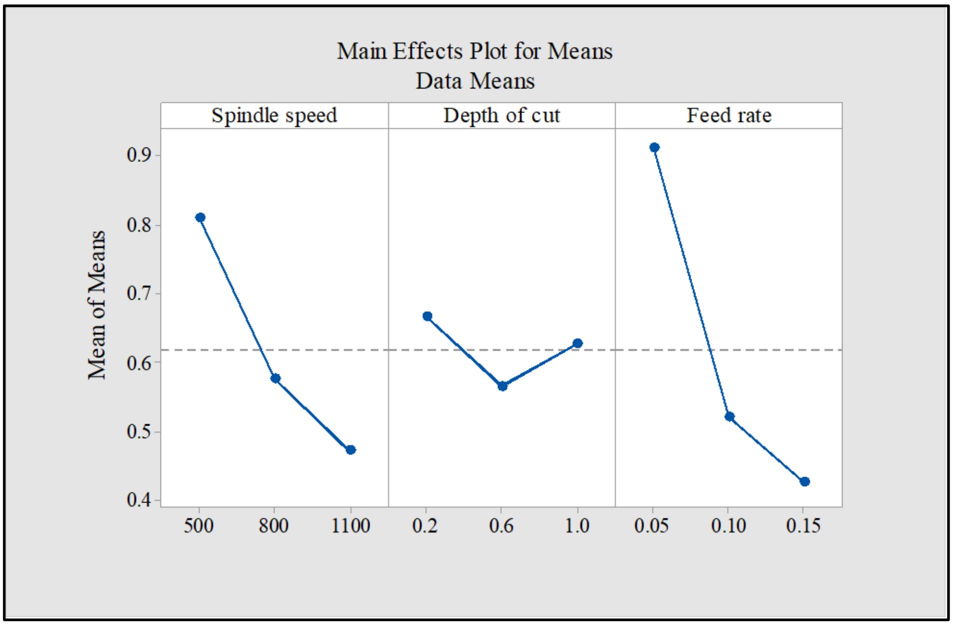

Figure 4.26. Main effect plot for means

Fig. 4.26 shows main effect plot for means of machining time. The minimum point of each graph indicates the preferred level of the factors that results in minimum machining time. If minimum machining time is required the spindle speed and feed rate values should be kept at the highest level and depth of cut should be kept on the middle level.

4.7.2. Interaction effects

In this topic interaction effects of cutting parameters with each other on machining time is discussed.

Fig. 4.27 shows the effect of feed rate on machining time at various levels of depth of cut. The graph reflects that when the depth of cut is set at 1 mm and the feed rate increases from 0.05 to 0.1 mm/rev the time required to complete turning operation was reduced from 0.817 to 0.433 minute and as the feed rate further increases to 0.15 mm/rev the machining time increased to 0.633 min. keeping depth of cut at 0.6 mm and increasing the feed rate from 0.05 to 0.15 mm/rev results in decreasing of machining time from 0.717 to 0.383 minute. In the same way the machining time is reduced from 1.2 to 0.267 minute as the feed rate is increased from lowest level to the highest level maintaining the depth of cut at 0.2 mm.

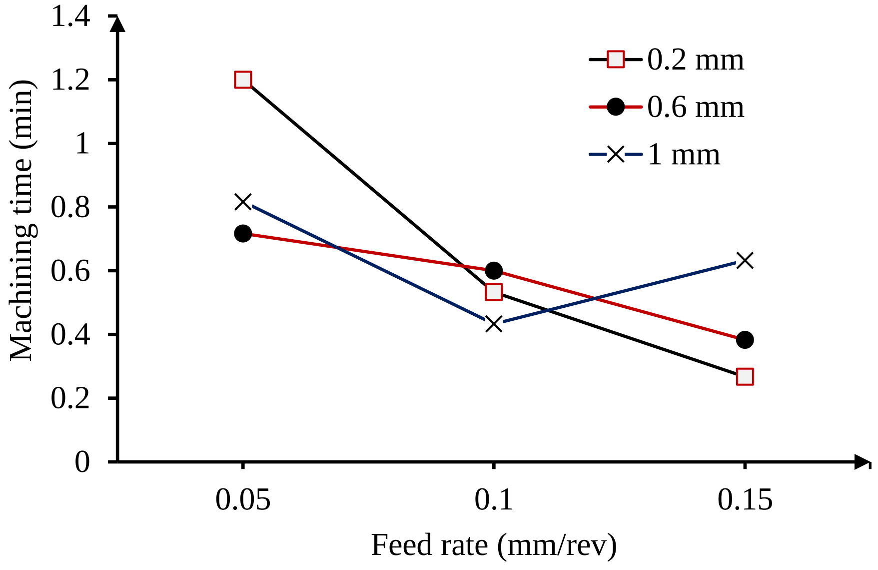

Figure 4.27. Effect of feed rate on machining time at different depth of cut

Effect of feed rate at different levels of spindle speed is shown on Fig. 4.28. The graph shows as increasing of the feed rate from lower level to the highest results in decreasing of the time to take the turning process from 0.717 to 0.267 minute and from 0.817 to 0.383 minute when the spindle speed is 1100 rpm and 800 rpm respectively. In case, if the spindle speed is 500 rpm is taken and increasing the feed rate from lower level to medium level results in decreasing of the time required to complete the operation from 1.2 to 0.6 minute and further increase of the feed rate results in slightly increasing of the time to 0.633 minutes.

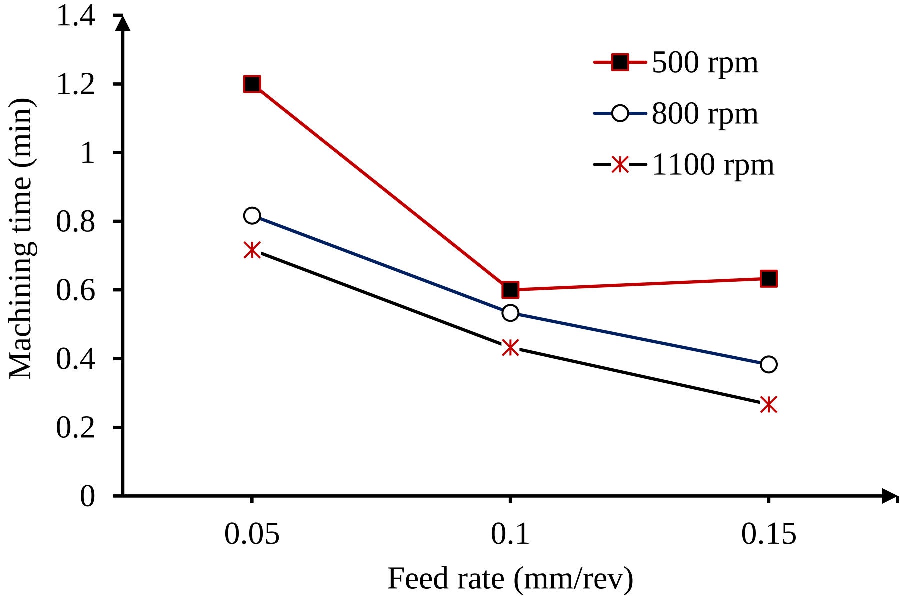

Figure 4.28. Effect of feed rate on machining time at different spindle speed

Effect of spindle speed on machining time at various level of depth of cut is shown on Fig.4.29. Keeping depth of cut at 0.2 mm and increasing spindle speed from 500 to 800, then 1100 rpm, machining time decreases from 1.2 to 0.533 then 0.267 minute. When depth of cut is 0.6 mm and spindle speed increase to 800 rpm machining time decreases from 0.633 to 0.383 minute, and when the spindle speed increases to 1100 rpm machining time increased to 0.717 minute. Maintaining depth of cut at 1 mm, machining time increased from 0.633 to 0.817 minutes when spindle speed increased from 500 to 800 rpm. Machining time was reduced to 0.433 minute as spindle speed increased to 1100 rpm.

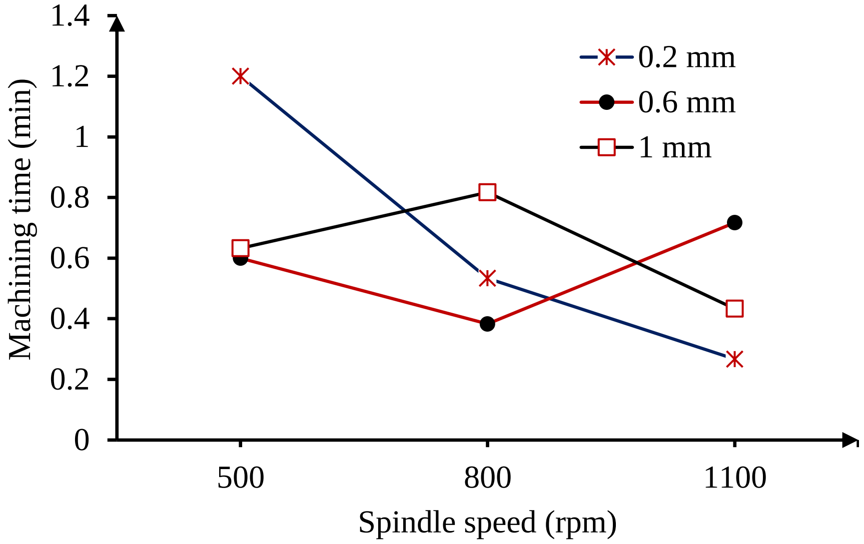

Figure 4.29. Effect of spindle speed on machining time at different depth of cut

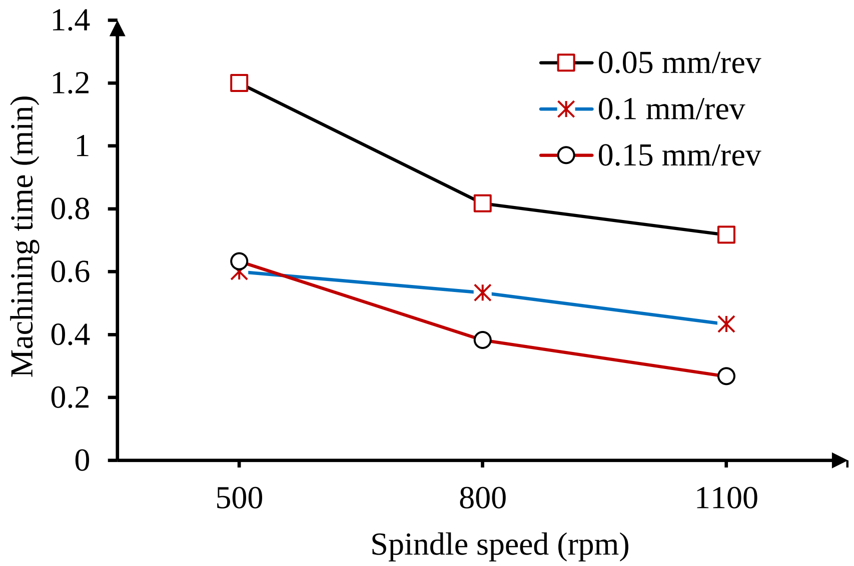

Figure 4.30. Effect of spindle speed on machining time at different feed rate

Fig. 4.30 shows effect of spindle speed on machining time at different feed rate. Taking feed rate at 0.05 mm/rev, when spindle speed increases from 500 to 800 and reaches 1100 rpm the machining time is decreased from 1.2 to 0.817 minute and reaches 0.717 minute respectively. Increasing spindle speed sequentially between its levels and keeping the feed rate constant at 0.1 mm/rev results in reduction of machining time complete turning operation from 0.63 to 0.533 minute and finally reduced to 0.433 minute. It can be concluded that keeping feed rate at constant level and increasing spindle speed results in decreasing of machining time.

4.7.3. Analysis of variance

Table 4.14 indicates the analysis of variance for machining time and the contribution of each factor on the machining time was presented in the table.

Table 4.14. Analysis of variance for cutting time

Source	DOF	SST	MSE	F-Value	P-Value	Contribution	Significance
Spindle speed	2	0.18023	0.090117	9.68	0.094	29.62%	Significant
Depth of cut	2	0.01524	0.007621	0.82	0.550	2.50%	Less significant
Feed rate	2	0.39441	0.197206	21.19	0.045	64.82%	Highly significant
Error	2	0.01861	0.009306			3.06%	
Total	8	0.60850				100.00%	

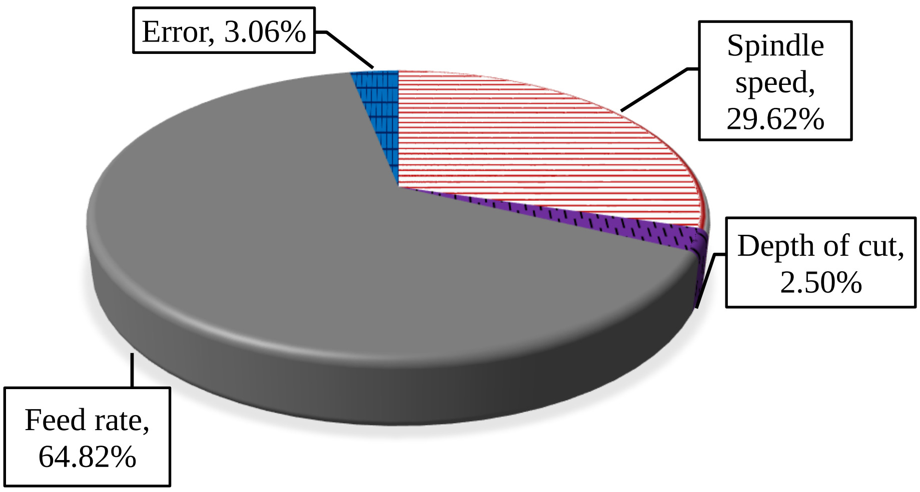

Figure 4.31. Percentage Contribution of Cutting Parameters on cutting time

From ANOVA table 4.14 and Fig. 4.31 it is observed that feed rate has significant effect (with percent contribution of 64.82 %) on machining time followed by spindle speed (with percent contribution of 29.62%) in dry turning of AISI 1026. Depth of cut has less contribution compared to those two factors.

4.8. Analysis of tool wear rate

Analyses of experimentally investigated cutting tool wear rate and its correlation with tool tip temperature generated values in dry turning of AISI 1026 steel was done under this topic.

In machining of material, tool wear will occur due to the friction and heat generated between the cutting tool and workpiece. Cutting tools experiences significant mechanical stress and thermal stress due to friction at the tool-work interface which can induce tool wear (Silva and Wall bank, 2017). Flank and crater wear are the most important types of wear normally experienced with the cutting tool. Flank wear is caused by friction between the flank face of the tool and the machined surfaces. It is caused by rubbing of the tool against the work piece at the interface, resulting in abrasive wear at high operating temperatures. The flank wear of cutting tool occurred in turning of the selected steel was observed using optical microscopy. Using the microscopy, the image of cutting tool insert at the flank face was taken for experiment number one and experiment number seven as shown on Fig. 4.32 and Fig. 4.33. Those two experiment numbers are selected since the lowest and highest tool tip temperature was occurred on these experimental runs.

Equation 4.4 can be used to calculate the rate of tool wear (Yousuf and Salim, 2018).

$$\text{Tool wear rate} = \frac{w_i - w_f}{t_{m} * \rho} \ (\text{mm}^3/\text{min}) \qquad (4.4)$$

Where: W_i= Initial Weight of the cutting tool insert (g); W_f = Final Weight measured of the cutting tool insert (g) ; ρ = Density of the cutting tool materials (g/mm^3); t_m= Machining time in min.

Using equation 4.4 and experimentally measured values, tool wear rate was calculated for each run and its result is tabulated in table 4.15 below.

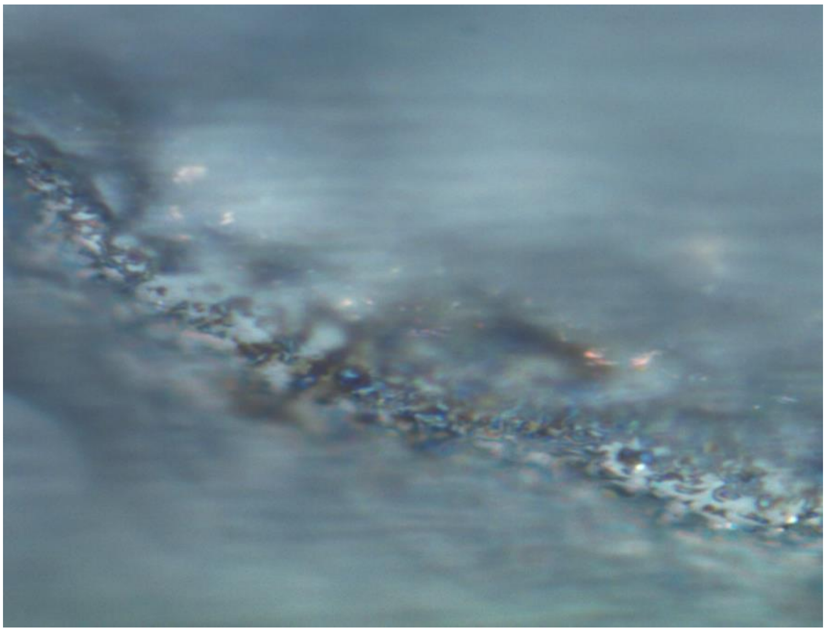

Figure 4.32. Microscopic view of flank wear for the first experiment

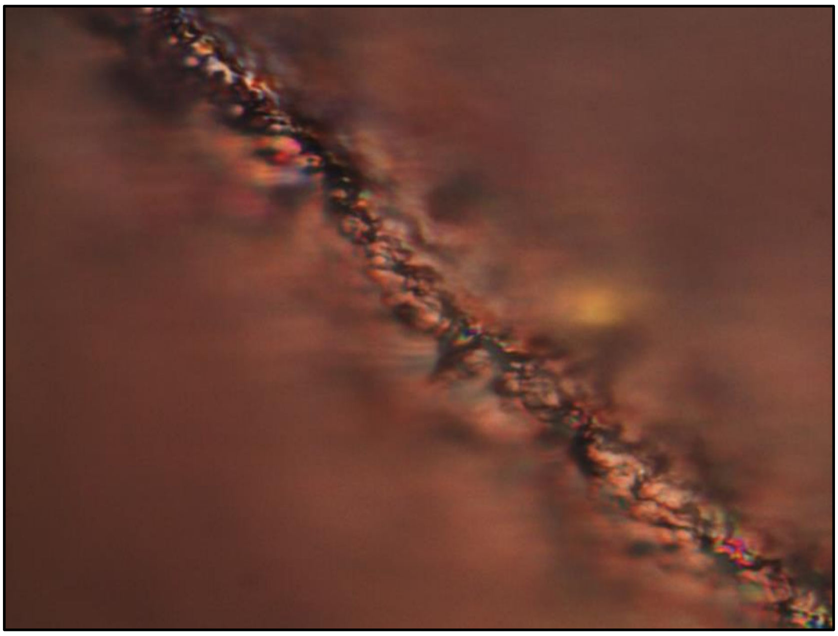

Figure 4.33. Microscopic view of flank wear for experiment number seven

From the figures it is observed that the cutting tool was worn at its flank side. Fig. 4.32 is image of flank wear at cutting parameters of 500 rpm, 0.2 mm and 0.05 mm/rev, and Fig. 4.33 is at spindle speed of 1100 rpm, depth of cut of 0.2 mm and feed rate of 0.15 mm/rev. The second image taken was at experimental number in which high tool tip temperature was recorded. Tool wear rate was done for each experimental run and its result is displayed in table 4.15.

Table 4.15. Tool wear rate value

Exp. No.	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Tool wear rate(mm^3/min)
1	500	0.2	0.05	0.855
2	500	0.6	0.1	1.077
3	500	1	0.15	1.317
4	800	0.2	0.1	2.280
5	800	0.6	0.15	2.610
6	800	1	0.05	2.179
7	1100	0.2	0.15	3.978
8	1100	0.6	0.05	3.206
9	1100	1	0.1	3.629

4.8.1. Analysis of mean

Table 4.16 and Fig. 4.34 shows response table for means and main effect diagram for means of tool wear rate respectively. It is observed minimum tool wear rate occurs when medium level of depth of cut and low level of spindle speed and feed rate are selected. Since this combination of cutting parameter was not exist in the orthogonal array designed, the value of tool wear rate is predicted by Minitab18 software and its value was found 0.765 mm^3/min. Tool wear rate at optimal surface roughness was found 3.130 mm^3/min. Spindle speed is the major factor that affects the rate of tool wear followed by feed rate. Increasing of spindle speed and feed rate increases the rate of cutting tool. These factors are also the main factors that affecting tool tip temperature. From this it easy to realize as tool tip temperature increases tool wear rate also increases and vice versa.

Table 4.16. Response table for means

Level	Spindle speed	Depth of cut	Feed rate
1	**1.083**	2.371	**2.080**
2	2.356	**2.298**	2.329
3	3.604	2.375	2.635
Delta	2.521	0.077	0.555
Rank	1	3	2

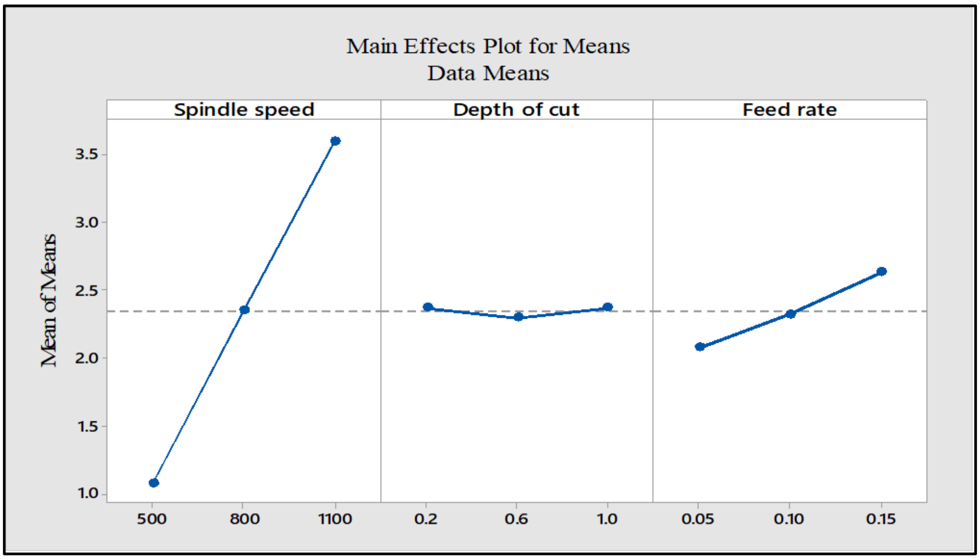

Figure 4.34. Main effect plot for means

4.8.2. Interaction effects

Interaction effects of cutting parameters on tool wear rate are discussed in this section.

Fig. 4.35 shows interaction effect of feed rate on tool wear rate at different spindle speed levels. Increasing of feed rate at the same spindle speed results in increasing of tool wear rate. Tool wear rate increases from 0.855 to 1.317 mm^3/min as feed rate increases from lowest l to the highest level and as spindle speed is kept at 500 rpm. Keeping spindle at 800 rpm and increasing feed rate between its two extremes result in increasing of tool wear rate from 2.179 to 2.61 mm^3/min. In the same way increasing the feed rate results in increasing of tool wear rate from 3.206 to 3.978 mm^3/min when the spindle speed is kept at 1100 rpm. The result reveals that increasing of feed rate keeping spindle speed constant results in increasing of tool wear rate.

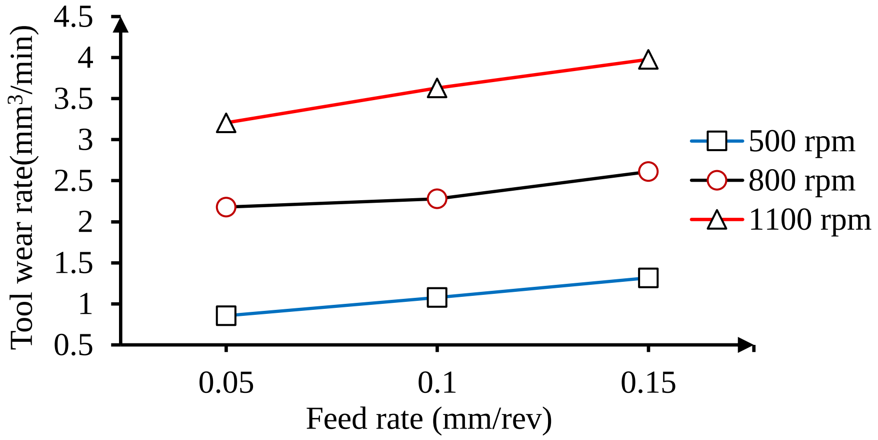

Figure 4.35. Effect of feed rate on tool wear rate at different spindle speed levels

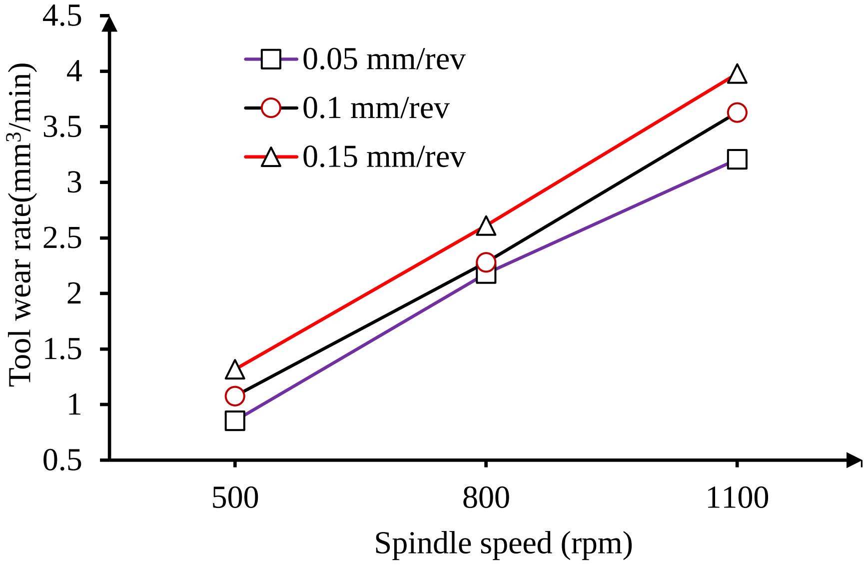

Figure 4.36. Effect of spindle speed on tool wear rate at different feed rate

Tool wear rate was observed as 0.855 mm^3/min when spindle speed was at 500 rpm and feed rate at 0.05 mm/rev as indicated on Fig. 4.36. Increasing the spindle speed to 800 rpm consequences an increase in tool wear rate to 2.179 mm^3/min and further increased to 3.206 mm^3/min as spindle speed increased to 1100 rpm. It was observed that increasing of spindle speed from 500 to 1100 rpm causes increasing of tool wear rate from 1.077 to 3.629 mm^3/min keeping feed rate at 0.1 mm/rev. when feed rate is maintained at 0.15 mm/rev and spindle speed increases to highest level tool wear rate reaches maximum (3.978 mm^3/min). From the figure it can be concluded that for all values of feed rate, increasing spindle speed results in increase of tool wear rate.

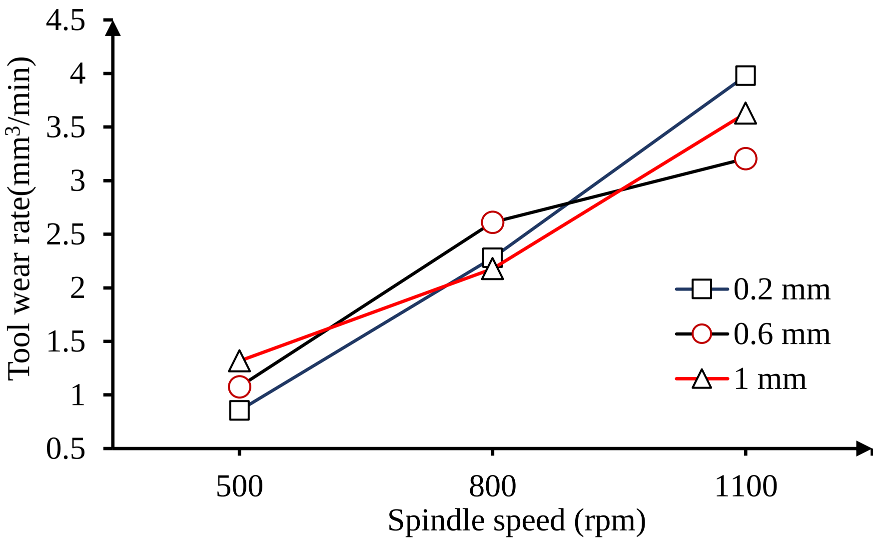

Figure 4.37. Effect of spindle speed on tool wear rate at different depth of cut

Effect of spindle speed on values of tool wear rate at different depth of cut was presented on Fig. 4.37. From the graph it can be concluded that having depth of cut constant at one of the levels and increasing spindle speed results in increasing of tool wear rate. This result is in line with work of (Yousuf and Salim, 2018), that concludes an increase in cutting speed values results in increased cutting tool wear rate and reduced tool life values.

4.9. Effect of tool tip temperature on tool wear rate

During machining operations heat is generated due to the friction occurred between cutting tool and the machined workpiece. The generated heat at the cutting zone has a strong effect on the tool wear, workpiece surface quality, produces hot chips that cause safety hazards to the machine operator, and can cause inaccuracies in work part dimensions due to thermal expansion of the work material (Prajapati *et al*.,2019). Effect of tool tip temperature on tool wear rate while turning of AISI 0126 steel in dry condition is discussed in this section. The relation between tool tip temperature and tool wear rate is shown in table 4.17 and Fig. 4.38.

Table 4.17. Effect of tool tip temperature on tool wear rate

Tool tip temperature (^{o}c)	36.4	38.6	42.3	43	43.8	47.4	59.3	63.2	66.7
Tool wear rate (mm^3/min)	0.855	1.077	1.317	2.179	2.28	2.61	3.206	3.629	3.978

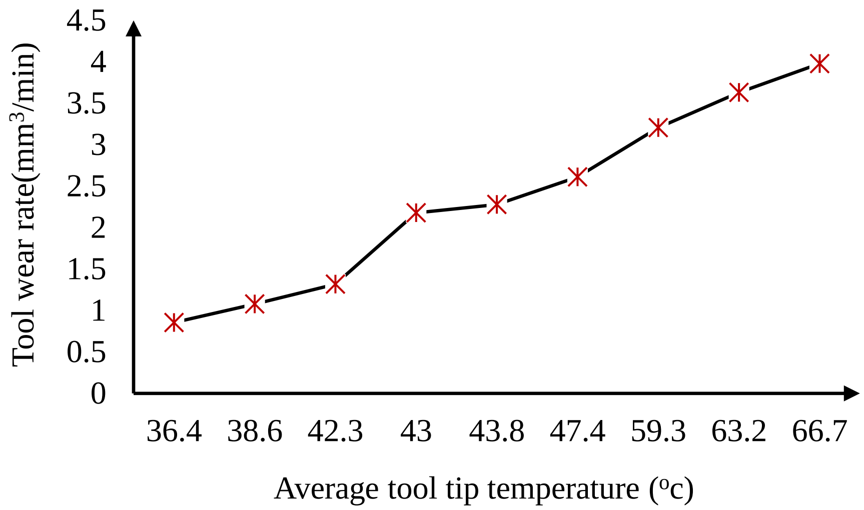

Figure 4.38. Effect of tool tip temperature on tool wear rate

As it is observed from Fig. 4.38, tool wear rate is increased as the value of tool tip temperature increases. Tool wear rate was 0.855 mm^3/min when the tool tip temperature was 36.4 ^{0}c and tool wear rate increased to 3.978 mm^3/min when the temperature of the tool tip reaches its maximum value (66.7 ^{o}c). Increase in tool tip temperature results in reduction of yield strength of the tool (Yousuf and Salim,2018) and this reduction of yield strength of the cutting tool consequences in greater wear rate at the tool tip. The factors that affect tool tip temperature also affects rate of tool wear. Spindle speed is the main factor that influences both, temperature generated at the tip of cutting tool and tool wear rate. So, to minimize tool wear rate, parameters that results in minimum temperature should have to be selected.

CHAPTER-5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This research was focused on studying the effect of cutting parameters on surface roughness, material removal rate, tool tip temperature, machining time, tool wear rate and optimizing the parameters to get optimal end response during dry turning of AISI 1026 steel with carbide cutting tool. Three main cutting parameters (spindle speed, depth of cut, and feed rate) with three levels for each are selected and their effect on end responses were studied. Levels of each factor were chosen based on knowledge obtained from the literature, tool manufacturer recommendations, and current industrial practice. Taguchi L9 orthogonal array has been utilized to study the effect and determine optimal cutting parameters and ANOVA was used to determine the role of each factor. Based on the results presented the conclusions are drawn as follows:

- ✓ Minimum surface roughness (1.063 µm) was attained at Spindle speed of 1100 rpm, 0.2 mm depth of cut and 0.05 mm/rev feed rate. This combination of levels was not in orthogonal array designed, as a result of this it is predicted by Minitab18 software and a conformation test was performed. The error between predicted value and confirmation test was small and this shows Taguchi-based orthogonal array experimentation was a successful and efficient technique to make analysis and prediction using minimum number of experiments.
- ✓ Spindle speed has significant effect on surface roughness with contribution of 63.78% followed by feed rate and depth of cut with contribution of 27.78 % and 6.21% respectively.
- ✓ Material removal rate was mainly affected by depth of cut followed by feed rate and spindle speed. Higher material removal rate is attained at highest levels of all factors. Value of material removal rate at optimum cutting parameters that leads to minimum surface roughness (spindle speed at 1100 rpm, depth of cut at 0.2 mm and feed rate at 0.15 mm/rev) was 4148.63 mm^3/min.
- ✓ Average tool tip temperature was significantly affected by spindle speed followed by feed rate and depth of cut. Increasing of spindle speed and feed rate results in increasing of tool tip temperature. Minimum average temperature was attained at 500 rpm spindle speed, 0.6 mm depth of cut and 0.05 mm/rev feed rate. Average tool tip

temperature at optimal cutting parameters result in minimum surface roughness was 57.6 ^{o}c.

- ✓ Feed rate have contribution of 64.82% in affecting machining time, while spindle speed contributes 29.62% and depth of cut contributes 2.50%. For selected optimal surface roughness value, machining time recorded was 0.783 minutes.
- ✓ Tool wear rate was significantly affected by spindle speed followed by feed rate and depth of cut. Wear rate of cutting tool found minimum at lowest level of all cutting parameters.
- ✓ Tool wear rate and tool tip temperature have a direct proportion. Increasing of tool tip temperature results in increasing of tool wear rate.

5.2. Recommendations

The following recommendations are made based on the study's findings and conclusions.

- ✓ The optimized turning parameters for dry turning of AISI 1026 steel can be used by the metal fabrication, automotive, manufacturing industries especially, Muger cement factory, etc. to achieve products with minimal surface roughness, machining time and tool wear rate.
- ✓ AISI 1026 steel was used in this research. This method can be applied to various materials to investigate the impact of cutting parameters on end response.

5.3. Scope for Future Work

- ✓ The effect of cutting parameters (spindle speed, depth of cut, and feed rate) was investigated in this study. This can be extended to the effect of additional parameters such as cutting tool material, cutting tool geometry, and tool coating.
- ✓ Future research work may be directed towards applying using other types of optimization techniques to further fine-tune results of end responses.
- ✓ Other output factors such as power usage, tool life, and cutting force exerted will be studied.

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REFERENCES

Abou-El-Hossein, K., & Kops, N. (2017). Investigation on the use of cutting temperature and tool wear in the turning of mild steel bars. journal of mechanical engineering and sciences, 11(4), 3038–3045. https://doi.org/10.15282/jmes.11.4.2017.7.0273

Aldolaimy, K. A. (2016). Effect of Cutting Parameters on Surface Roughness in Turning Operations. Al-Qadisiyah J. Eng. Sci, 9(4).

Angwenyi, N., Senga, N., Ronoh, N., Mwema, F., Akinlabi, E., & Tanya, B. (2021). The effects of machining parameters on conventional machining: An overview. Materials Today: Proceedings, 44, 1540–1542. https://doi.org/10.1016/j.matpr.2020.11.751

Ashisharao[1], M. G. A., & N, D. S. (2018). A Review on: Parametric study for Optimization of CNC turning process parameters for surface roughness using ANOVA.

Asilturk, I., and Akkuş, H. (2011). Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method.

ASME/ANSI B46.1 (1985) Surface texture (surface roughness, waviness and lay). ASME, New York.

Awopetu, O. O., & Ayodeji, S. P. (2008). Effect of type of workpiece material on chip formation process. AU Journal of Technology, 11(3), 181-186.

Babu, R., Smart, D. R., Mahesh, & Smart, J. J. (2006). application of heuristic techniques and effect of parameter on turning and facing operation-a review (2010-2015).

Bhavani, T. K., Satyanarayana, K., Kumar, G. S. V., & Kumar, I. A. (2017). Optimization of material removal rate and surface roughness in turning of aluminum, copper and gunmetal materials using RSM. Int J Eng Res Technol (IJERT), 6(02).

Boki, D. (2021). Comparison of Effect of Cutting Parameters during Dry and Wet Turning of AISI 1020 Steel (Doctoral dissertation, ASTU).

Butola, R., Jitendrakumar, Vaibhavkhanna, Ali, P., & Khanna, V. (2017). Effecton Surface Properties OF Mild Steel During Dry Turning & Wet Turning on Lathe. Materials Today: Proceedings, 4(8), 7892–7902. https://doi.org/10.1016/j.matpr.2017.07.125

Chandra, P., Rao, C. P., & Kiran, R. (2018). Influence of machining parameter on cutting force and surface roughness while turning alloy steel. Materials Today: Proceedings, 5(5), 11794-11801.

Chikalthankar, S. B., Kakade, R. B., & Nandedkar, V. M. (2014). Investigation and optimization of tool tip temperature in turning of OHNS. International Journal of Engineering Research & Technology (IJERT), 4(10), 1039-1043.

Chowdary, M. S. P., Sohail, S. W., Sajidh, S. K., & Krishna, k. s. international journal of engineering sciences & research technology optimization of surface roughness and material removal rate in turning operation of mild steel using taguchi method.

Clares, J. M., Vazquez, J, Gomez-Parra, A., Puerta, F., & Marcos, M. (2015, October). Experimental methodology for evaluating workpieces surface integrity in dry turning of aerospace alloys. In Proceedings of the 26th DAAAM International Symposium on Intelligent Manufacturing and Automation, Zadar, Croatia (pp. 21-24).

Da Silva, M. B., & Wall bank, J. (2017). Cutting temperature: prediction and measurement methods A review. Journal of materials processing technology, 88(1-3), 195-202

Dan, L., & Mathew, J. (1990). Tool wear and failure monitoring techniques for turning review. International Journal of Machine Tools and Manufacture, 30(4), 579-598.

Dasgupta, S., & Mukherjee, S. (2016, September). Effects of machining parameters on tool life and its optimization in turning mild steel with brazed carbide cutting tool. In IOP Conference Series: Materials Science and Engineering IOP Publishing.

Dasgupta, S., & Mukherjee, S. (2016, September). Effects of machining parameters on tool life and its optimization in turning mild steel with brazed carbide cutting tool. IOP Conference Series: Materials Science and Engineering, 012005.

Davis, R., Madhukar, J. S., Rana, V. S., & Singh, P. (2012). Optimization of cutting parameters in dry turning operation of EN24 steel. International Journal of Emerging Technology and Advanced Engineering, 2(10), 559-63.

Davis, R., Madhukar, J. S., Rana, V. S., & Singh, P. (2012). Optimization of cutting parameters in dry turning operation of EN24 steel. International Journal of Emerging Technology and Advanced Engineering, 2(10), 559-63.

Dhar, N., Ahmed, M., & Islam, S. (2007). An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel. International Journal of Machine Tools and Manufacture, 47(5), 748–753. https://doi.org/10.1016/j.ijmachtools.2006.09.017.

Ebrahim, K. T., Jiru, M. G., & Sisay, A. (2020). Optimization of Cutting Parameters for Free Cutting Brass (CuZn35Pb3) Using Taguchi Method. Ethiopian Journal of Sciences and Sustainable Development, 7(2), 93-102.

Fuzhao, J., and Liu, W. (2012). Multi-objective optimization of cutting parameters in high-speed milling based on grey relational analysis coupled with principal component analysis. Frontiers of Mechanical Engineering, 7(4), 445-452.

Ginta, T. L., Amin, A. K. M. N., Radzi, H, & Lajis, M. A. (2009). Tool life prediction by response surface methodology in end milling titanium alloy Ti-6Al-4V using uncoated WC-Co inserts. European Journal of Scientific Research, 28(4), 533-541.

Goyal, S., Kandra, V. S., & Yadav, P. (2016). Experimental study of turning operation and optimization of MRR and surface roughness using taguchi method.

Haresh Y Valera, Sanket N Bhavsar, (2019). Experimental investigation of surface roughness and power consumption in turning operation of EN31 alloy steel, procedia technology, volume 14, pp 528-534, 2014.

Iso, I. (1993). 3685: tool-life testing with single-point turning tools. *International Organization for Standardization (ISO): Geneva, Switzerland*.

Jaiganesh, V., Yokesh Kumar, B., Sevvel, P., & Balaji, A. (2017). Optimization of process parameters on commercial mild steel using taguchi technique. International Journal of Engineering & Technology, 7(1.1), 138. https://doi.org/10.14419/ijet.v7i1.1.9213

Jha, S. K. (2014). Optimization of process parameters for optimal MRR during turning steel bar using taguchi method and ANOVA. International journal of mechanical engineering and robotics research, 3(3), 231.

Karim, Z. A., Azuan, S., & Yasir, A. (2013). A study on tool wear and surface finish by applying positive and negative rake angle during machining.

Karthik, M., Raju, V., Reddy, K. N., Balashanmugam, N., & Sankar, M. (2020). Cutting parameters optimization for surface roughness during dry hard turning of EN 31 bearing steel using CBN insert. Materials Today: Proceedings, 26, 1119–1125. https://doi.org/10.1016/j.matpr.2020.02.224

Karthik, M., Raju, V., Reddy, K. N., Balashanmugam, N., & Sankar, M. (2020). Cutting parameters optimization for surface roughness during dry hard turning of EN 31 bearing steel using CBN insert. Materials Today: Proceedings, 26, 1119–1125. https://doi.org/10.1016/j.matpr.2020.02.224

Khamel, S., Ouelaa, N., & Bouacha, K. (2012). Analysis and prediction of tool wear, surface roughness and cutting forces in hard turning with CBN tool. Journal of mechanical science and technology, 26(11), 3605-3616.

Khan, M. A., Kittur, J. K., & Kohir, V. D. (2015). Study and Analysis of Effect of Cutting Parameters on Cutting Forces and Surface Roughness. Advanced Engineering and Applied Sciences, An International Journal, 5(3), 63-73.

Khan, Z. A., Grover, M., & Nazir, M. H. (2015). The implications of wet and dry turning on the surface quality of EN8 steel. In Transactions on Engineering Technologies (pp. 413-423). Springer, Dordrecht.

Krishnaiah, P. Shahabudeen (2012), ' Applied design of experiments and Taguchi methods', PHI Learning, New Delhi-110001

Kirubel, T. (2021). *Experimental Investigation and Parametric Optimization of EN-8 Steel using Dry Turning for Enhanced Surface Finish* (Doctoral dissertation, ASTU).

Kumar, T. S., Mahadevan, G., & Vikraman, T. R. (2014). Evaluation of Surface Finish on Machining of Mild Steel Using High Speed Steel Tool in Lathe using Coolant. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN, 2278-1684.

Lalwani, D. I., Mehta, N. K., & Jain, P. K. (2008). Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel. Journal of materials processing technology, 206(1-3), 167-179.

Lo, S. P. (2000). An analysis of cutting under different rake angles using the finite element method. Journal of Materials Processing Technology, 105(1-2), 143-151.

Makadia, A. J., & Nanavati, J. I. (2013). Optimization of machining parameters for turning operations based on response surface methodology. Measurement, 46(4), 1521-1529.

Marko, H., Simon, K., Tomaz, I., Matej, P., Joze, B., & Miran, B. (2014). Turning parameters optimization using particle swarm optimization. Procedia Engineering, 69, 670-677.

Mikell P. Groover, (2013). Fundamental of modern manufacturing; material, processes, and systems, fifth edition, pp. 606

Moganapriya, C., Rajasekar, R., Ponappa, K., Venkatesh, R., & Jerome, S. (2018). Influence of Coating Material and Cutting Parameters on Surface Roughness and Material Removal Rate in Turning Process Using Taguchi Method. Materials Today: Proceedings, 5(2), 8532–8538. https://doi.org/10.1016/j.matpr.2017.11.550.

Naik, V. R., & Magdum, V. B. (2018). Design and development of a blower impeller by reverse engineering for noise reduction using CFD. International Journal of Applied Engineering Research, 13(11), 9982-9987.

Nair, Mahipal B. Padhiyar1 Prof Vidya (2017). "Analysis of Surface Roughness with Different Cutting Parameters in Turning: A Review."

Panneerselvam, T., Kandavel, T. K., Chaitanya, T. K., & Tarun, K. S. (2021). Cutting tool performance analysis of P/M alloy steel under turning of copper material. Journal of Mechanical Science and Technology, 35(9), 3951–3958. https://doi.org/10.1007/s12206-021-0808-5.

Patwari, A. U., Mahmood, M. N., & Arif, M. D. (2012). Improvement of machinability of mild steel during turning operation by magnetic cutting. International Journal on Advanced Science Engineering Information Technology, 2(3).

Potta, S. (2019). Effect of cryogenic coolant on turning performance: a comparative study. SN Applied Sciences, 1(1), 1-9.

Prajapati, K., Prajapati, K., Srivastav, K., & Patel, V. (2019). Experimental investigation on turning parametersduring turning of mild steel for cutting forces using design of experiment (doe). IJRAR-International Journal of Research and Analytical Reviews (IJRAR), 6(1), 175-181.

Quintana, G., & Ciurana, J. (2011). Chatter in machining processes: A review. International Journal of Machine Tools and Manufacture, 51(5), 363-376.

Radha Krishnan, B., Vijayan, V., Parameshwaran Pillai, T., & Sathish, T. (2019). Influence of surface roughness in turning process — an analysis using artificial neural network. Transactions of the Canadian Society for Mechanical Engineering, 43(4), 509–514. https://doi.org/10.1139/tcsme-2018-0255

Rajasekaran, T., Palanikumar, K., & Arunachalam, S. (2013). Investigation on the Turning Parameters for Surface Roughness using Taguchi Analysis. Procedia Engineering, 51, 781–790. https://doi.org/10.1016/j.proeng.2013.01.112

Rewatkar, S. A., Deshbhratar, N. A., Kawale, A. P., Kardam, A. M., & Naik, A. D. (2017). Review of Influence of Different Cutting Angles of Single Point Cutting Tool on Turning Operation. International Research Journal of Engineering and Technology (IRJET), 4(2), 1224-1228.

Sahithi, T. Malayadrib, & Srilatha, N. (2019). Optimization of Turning Parameters On Surface Roughness Based on Taguchi Technique. Materials Today: Proceedings, 18, 3657–3666. https://doi.org/10.1016/j.matpr.2019.07.299

Sahin, Y., & Motorcu, A. R. (2005). Surface roughness model for machining mild steel with coated carbide tool. Materials & design, 26(4), 321-326.

Sahoo, P. (2011). Optimization of turning parameters for surface roughness using RSM and GA. Advances in Production Engineering & Management, 6(3). Transactions of the Canadian Society for Mechanical Engineering, 43(4), 509–514.

Şap, E., Usca, U. A., Gupta, M. K., & Kuntoğlu, M. (2021). Tool wear and machinability investigations in dry turning of Cu/Mo-SiCp hybrid composites. The International Journal of Advanced Manufacturing Technology, 114(1–2), 379–396.

Senthilkumar, N., & Tamizharasan, T. (2014). Effect of Tool Geometry in Turning AISI 1045 Steel: Experimental Investigation and FEM Analysis. Arabian Journal for Science and Engineering, 39(6), 4963–4975. https://doi.org/10.1007/s13369-014-1054-2

Shahid, M. (2020). Optimization of Turning Process Parameters in Machining Heat Treated Steel. International Journal for Research in Applied Science and Engineering Technology, 8(9), 121–125. https://doi.org/10.22214/ijraset.2020.31339

Sharma, K., Mahto, D. G., & Sen, S. S. (2013). In metal turning, effect of various parameters on cutting tool: A Review. International journal of application or innovation in engineering & management (IJAIEM), 2(8).

Shokoohi, Y., Khosrojerdi, E., & Rassolian Shiadhi, B. (2015). Machining and ecological effects of a new developed cutting fluid in combination with different cooling techniques on turning operation. Journal of Cleaner Production, 94, 330–339. https://doi.org/10.1016/j.jclepro.2015.01.055

Singh, H., Sharma, S., Awasthi, V., Kumar, V., & Singh, S. (2013). Study of Cutting Parameters on Turning using EN9. International Journal of Advance Industrial Engineering, 1(2), 40–42

Singh, P., & Channi, A. S. A (2014). Review on the Influence of Input Parameters in Turning Process.

Singh, R., Shadab, M., & Rai, R. (2018). Optimization of machining process parameters in conventional turning operation of Al5083/B4C composite under dry condition. Materials Today: Proceedings, 5(9), 19000–19010. https://doi.org/10.1016/j.matpr.2018.06.251

Somashekara, H. M., & Swamy, N. L. (2012). Optimizing surface roughness in turning operation using Taguchi technique and ANOVA. International Journal of engineering science and technology, 4(05), 1967-1973.

Suleiman Abdulkareem, Bashir Mohamed (2015). Study of cutting speed on surface roughness and chip formation when machining nickel-based alloy, Journal of Mechanical Science and Technology, Vol. 24 (5), pp. 1053 – 1059, 2010.

Swain, S., Chattarjee, S., Panigrahi, I., & Sahoo, A. K. (2018). Cutting tool vibration analysis for better surface finish during dry turning of mild steel. Materials Today: Proceedings, 5(11), 24605-24611.

Tulasi, R., Singh, R., & Ali, M. I. (2018). Optimizing Surface Roughness in Turning Operation Using Taguchi Technique. Materials Today: Proceedings, 5(9), 19043–19048. https://doi.org/10.1016/j.matpr.2018.06.256

Usca, Ü. A., Uzun, M., Kuntoğlu, M., Sap, E., & Gupta, M. K. (2021). Investigations on tool wear, surface roughness, cutting temperature, and chip formation in machining of Cu-B-CrC composites. The International Journal of Advanced Manufacturing Technology, 116(9), 3011-3025.

Usman, K. M. (2012). Effects of tool rake angle on tool life in turning tools. Int J Sci Eng Res, 3(4), 1-6.

Yan, J., and Li, L. (2013). Multi-objective optimization of milling parameters–the trade-offs between energy, production rate and cutting quality. Journal of Cleaner Production, 52, 462-471.

Yan, P., Rong, Y., & Wang, G. (2015). The effect of cutting fluids applied in metal cutting process. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230(1), 19–37. https://doi.org/10.1177/0954405415590993

Yemul, M. N. N., & Deshpande, G. R. (2021). Literature Review on Tool Wear in Turning Operation of Aluminium. International Journal of Innovations in Engineering Research and Technology, 8(2), 15-17.

Yousuf Al Kindi, M. R., & Salim, R. K. (2018). Tool Wear Investigation in CNC Turning Operation. In *Proceedings of the World Congress on Engineering* (Vol. 2).

Zain, A. M., Haron, H., and Sharif, S. (2010). Application of GA to optimize cutting conditions for minimizing surface roughness in end milling machining process. Expert Systems with Applications, 37(6), 4650-4659.

APPENDIXES

Appendix A. Levels of factors with their experimental values and SNR values on Minitab18

Minitab - Minitab finaal 1.MPJ - [Worksheet 1 ***]

File Edit Data Calc Stat Graph Editor Tools Window Help Assistant

→	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	Exp no	Spindle speed	Depth of cut	Feed rate	surface roughness	MRR (mm3/min)	Temprature (c)	machining time	tool wear	SNR Ra	SNR MRR	SNR T
1	1	500	0.2	0.05	1.833	546.6	36.4	1.200	0.855	-5.26325	54.7540	-54.7540
2	2	500	0.6	0.10	2.107	3242.1	38.6	0.600	1.077	-6.47329	70.2166	-70.2166
3	3	500	1.0	0.15	2.787	8011.1	42.3	0.633	1.317	-8.90274	78.0738	-78.0738
4	4	800	0.2	0.10	1.723	1749.2	43.8	0.533	2.280	-4.72571	64.8570	-64.8570
5	5	800	0.6	0.15	2.130	7781.1	47.4	0.383	2.610	-6.56759	77.8208	-77.8208
6	6	800	1.0	0.05	1.700	4272.6	43.0	0.817	2.179	-4.60898	72.6138	-72.6138
7	7	1100	0.2	0.15	1.510	3607.8	66.7	0.267	3.978	-3.57954	71.1449	-71.1449
8	8	1100	0.6	0.05	1.243	3566.3	59.3	0.717	3.206	-1.88942	71.0444	-71.0444
9	9	1100	1.0	0.10	1.387	11749.6	63.2	0.433	3.629	-2.84153	81.4004	-81.4004
10												

Appendix B. Response table for signal to noise ratio and mean of average surface roughness

Taguchi Analysis: surface roughness versus Spindle ... of cut, Feed rate

Response Table for Signal to Noise Ratios

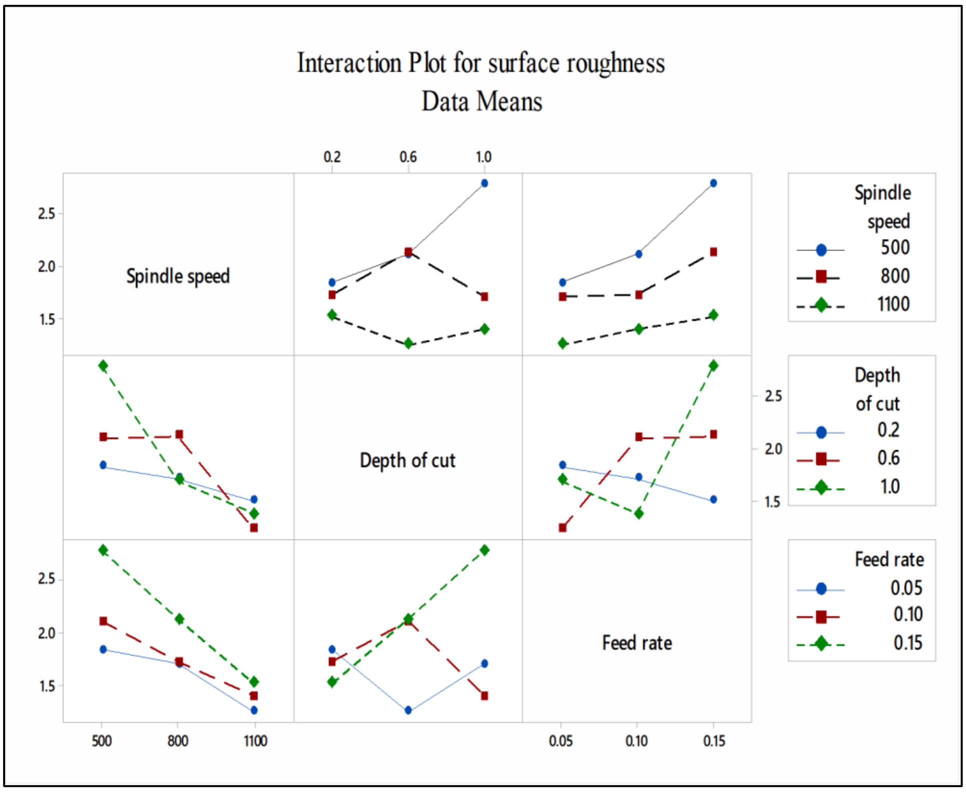
Smaller is better

Level	Spindle speed	Depth of cut	Feed rate
1	-6.880	-4.523	-3.921
2	-5.301	-4.977	-4.680
3	-2.770	-5.451	-6.350
Delta	4.110	0.928	2.429
Rank	1	3	2

Response Table for Means

Level	Spindle speed	Depth of cut	Feed rate
1	2.242	1.689	1.592
2	1.851	1.827	1.739
3	1.380	1.958	2.142
Delta	0.862	0.269	0.550
Rank	1	3	2

Appendix C. Interaction plots of surface roughness



Appendix D. Interaction plots of material removal rate