RESPONSE SURFACE OPTIMIZATION OF MACHINING PARAMETERS IN TURNING OF SS316 CHROMIUM-NICKEL ALLOY

A Project report submitted

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

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Project Report entitled "**RESPONSE SURFACE OPTIMIZATION OF MACHINING PARAMETERS IN TURNING OPERATION OF SS316 CHROMIUM-NICKEL ALLOY**" being submitted by **T. KRISHNA VAMSI (318126520053), G. SHANMUKHA SRINIVAS RAO (319126520L13), K. TARUN (318126520024), A. ROHITH (319126520L14), P. CHARLIE SWARAJ (318126520042)** in partial fulfilments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**. It is the work of bonafide, carried out under the guidance and supervision of, **Mr. D.S. Sai Ravi Kiran M. Tech, (PhD)**, Assistant Professor, **DEPARTMENT OF MECHANICAL ENGINEERING** during the academic year of 2018-2022.

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ABSTRACT

In the present days, every manufacturing sector is thriving hard to survive in the competitive nature in spite of experiencing the thrust on improved productivity, optimum quality with reasonable cost. Updates in the modern technology and huge investments are the call for progressing with the modern manufacturing systems. Under these circumstances the effective utilization of resources to the optimum level is utmost important. On the other hand, the innovative nature of stainless alloys is fetching more and more popular because of their high tensile strength, easily formable and fabricated, environmentally friendly. SS-316 alloy materials have the characteristics of corrosion resistance, and low maintenance.

Machining operations are inevitable in fabrication of the product to the required dimension and shape. Turning operation is one of the most accepted machining courses in the metal cutting process. As the economies of the operations depend on the input and output parameters, in order to obtain the reasonable product, one has to locate the set of input machining parameters with reference to the resultant parameters. This requires the optimization of cutting parameters as the key component in preparation of machining processes. To optimize the machining operations the quantitative methods have been followed by considering a multi objectives, such as minimizing the cutting tool temperature and surface roughness and maximizing material removal rates. The machining process is identified as a multiple-objective optimization problem with restriction of non-equating and mainly with the conflicting objectives production rate, operation cost and quality of machining where these objectives are influenced as a function of the cutting speed, feed rate and depth of cut usually.

Out of all the outcome parameters surface roughness and dimensional accuracy are being considered as they have direct implication on product quality and production rate. Optimal control factors have been determined using Response Surface Methodology. Later ANOVA analysis is done to determine the contribution percentage of each input factors that affects the output parameter in one or the other way. The tests are performed on AISI 316 grade of Stainless-Steel using tungsten carbide tipped tool as cutting tool.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

Metal cutting is very effective and one of the most commonly used form of metal removal in any engineering or manufacturing industries. Turning operation is a type of metal removal processes which tends to remove excess material using a cutting tool of hardness greater than the work piece. The primary objective of any metal removal operation is to produce products with lower power consumption and high metal removal rate. Optimization of machining parameters (control factors) plays very crucial role in achieving desired goal. The process of optimization usually involves the optimal selection of control factors viz. cutting speed, feed rate and depth of cut. Optimization is carried out independently for every operation on every machine. All manufacturing industries work with different varieties of products and hence use different variation of machines, hence optimization of each such machines with its work material are necessary and the results of optimized parameters do vary from one another in many ways depending on working conditions. Thus, optimization provides significant efficient result leading to high production with lower power consumption and improved product quality. Significant and improved process efficiency can only be achieved by optimization of process parameter. Machining is defined as a metal removal process in which the excess metal from the work piece is removed in the form of chips by means of single or multiple point cutting tool of hardness greater than the work piece.

1.1 LATHE

A lathe is a machine tool that rotates a workpiece about an axis of rotation to perform various operations such as cutting, sanding, knurling, drilling, deformation, facing and turning with tools that are applied to the workpiece to create an object with symmetry about that axis.

1.2 COMMON TYPES OF LATHES

i. Center lathe or engine lathe machine
ii. Speed lathe machine
iii. Capstan and turret lathe machine
iv. Bench lathe machine

v. Special lathe machine
vi. Automatic lathe machine
vii. CNC lathe machine

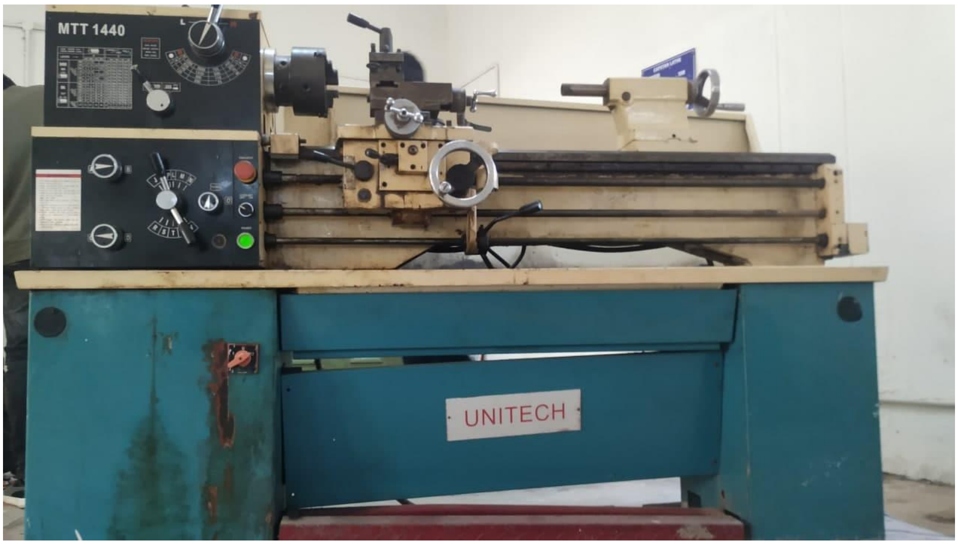

Figure 1.1 Lathe

1.2.1 Center lathe or engine lathe machine

This is a type of lathe that is currently widely used and can perform operations such as turning, end face, grooving, knurling, and threading. The feed mechanism of the engine lathe can operate the cutting tool in both the longitudinal and lateral directions. The center lathe can be divided into belt drive, motor drive and reducer depending on the drive source.

1.2.2 Speed lathe machine

The high-speed lathe can also be called a wood lathe, which can be operated at high speed and is operated manually. The speed range for high-speed lathes is approximately 1200 to 3600 RPM. This lathe is used for the rotation, centering, polishing and machining of wood.

1.2.3 Capstan and turret lathe machine

Capstan and turret lathes are improvements in engine lathes that can be used for high volume production and for large jobs. The head of the machine tool is a hexagonal head, which can be rotated to change the operation without manual change, including turning, end face, boring and reaming.

1.2.4 Toolroom lathe machine

The tool room lathe is similar to the engine lathe, but its parts are manufactured with great precision and in order, so this machine is used for high precision grinding machining.

1.2.5 Bench lathe machine

The small size of the bench lathe can be used for smaller and more precise work, with parts similar to engine lathes and high-speed lathes.

1.2.6 Automatic lathe machine

The automatic lathe can perform work automatically and can be used for mass production. The automatic machine will automatically change without having to change the tool manually. The advantage is that an operator can handle the operation of multiple machines at the same time. The automatic lathe is a high-speed and heavy-duty machine.

1.2.7 Special lathe machine

Special lathes are used to perform special operations that are not possible with the rest of the lathe. Special lathes include vertical lathes, wheeled lathes, T-type lathes, multi-axis lathes, production lathes, duplex or tracer lathes, etc., which are known for their heavy-duty production of the same parts.

1.2.8 CNC lathe machine

The CNC lathe is used to control the operation of the machine tool through a computer program. Once the program is input in steps, mass production can be performed with high precision and high speed, and once the operation code is set, it can be produced without re-entering the next time. CNC lathes are the most advanced types of lathes available today, and the tolerances of the parts they produce are extremely precise.

1.3 WHAT IS TURNING?

Turning is the most common lathe machining operation. During the turning process, a cutting tool removes material from the outer diameter of a rotating workpiece. The main objective of turning is to reduce the workpiece diameter to the desired dimension.

Different sections of the turned parts may have different outer dimensions. The transition between the surfaces with two different diameters can have several topological features, namely step, taper, chamfer, and contour. To produce these features, multiple passes at a small radial depth of cut may be necessary.

1.3.1 Step Turning

Step turning creates two surfaces with an abrupt change in diameters between them. The final feature resembles a step.

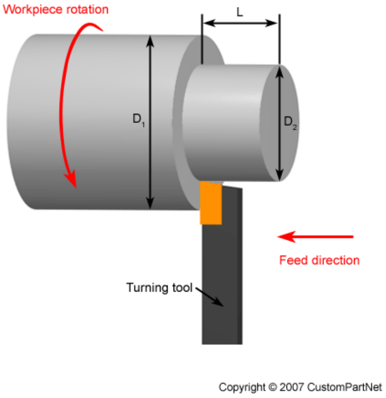

Fig. 1.2 Step Turning

1.3.2 Taper Turning

Taper turning produces a ramp transition between the two surfaces with different diameters due to the angled motion between the workpiece and a cutting tool.

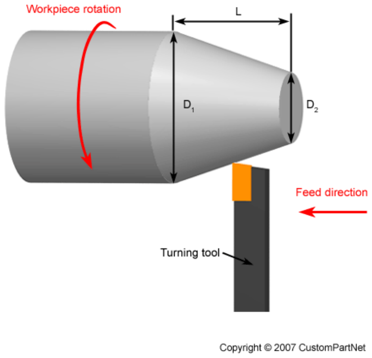

Fig. 1.3 Taper Turning

1.3.3 Chamfer Turning

Similar to the step turning, chamfer turning creates angled transition of an otherwise square edge between two surfaces with different turned diameters.

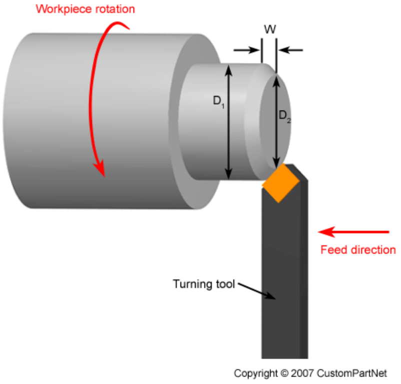

Fig. 1.4 Chamfer Turning

1.3.4 Contour Turning

In contour turning operation, the cutting tool axially follows the path with a predefined geometry. Multiple passes of a contouring tool are necessary to create desired contours in the workpiece. However, form tools can produce the same contour shape is a single pass.

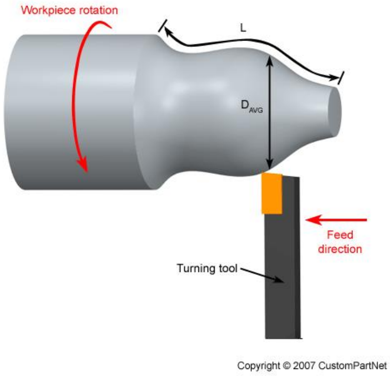

Fig. 1.5 Contour Turning

1.4 PROCESS PARAMETERS

In a turning operation, it is important task to select cutting parameters for achieving high cutting performance. In this study, the considered cutting parameters are **Spindle Speed, Feed Rate, Depth of cut.** Basically, surface roughness, material removal rate (MRR), tool temperature is strongly correlated with cutting parameters such as cutting speed, feed rate, and depth of cut. Proper selection of the cutting parameters based on the parameter design of the Taguchi method is adopted in this project to improve surface roughness, metal removal rate, cutting tool temperature in a turning operation.

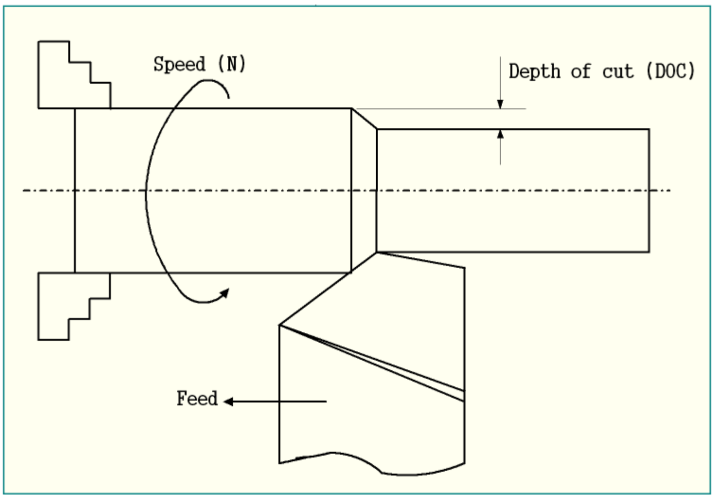

Fig. 1.6 Process or Machining Parameters for Turning Operation

1.4.1 Spindle Speed

Spindle speed (also called surface speed or cutting speed) is the speed difference (relative velocity) between the cutting tool and the surface of the workpiece it is operating on. It is expressed in units of distance across the workpiece surface per unit of time, typically surface feet per minute (sfm) or meters per minute (m/min).

1.4.2 Feed Rate

Feed rate (or called simply feed) is the relative velocity at which the cutter is advanced along the workpiece; its vector is perpendicular to the vector of cutting speed. Feed rate units depend on the motion of the tool and workpiece; when the workpiece rotates (e.g., in turning), the units are almost always distance per spindle revolution (inches per revolution [in/rev or ipr] or millimeters per revolution [mm/rev]).

1.4.3 Depth of Cut

It is the total amount of metal removed per pass of the cutting tool. It is expressed in mm. It can vary and depending upon the type of tool and work material. Mathematically, it is half of difference of diameters.

1.5 OUTPUT PARAMETERS

1.5.1 Material Removal Rate (MRR)

MRR is the volume of material removed per unit time when performing machining operations such as using a lathe or milling machine. The more material removed per minute, the higher the material removal rate. MRR is a single number that enables you to do this. It is a direct indicator of how efficiently you are cutting, and how profitable you are. MRR is the volume of material removed per minute. The higher your cutting parameters, the higher the MRR. Phrased in another way, the MRR is equal to the volume of residue formed as a direct result of the removal from the workpiece per unit of time during a cutting operation.

The material removal rate in a work process can be calculated as the depth of the cut, times the width of the cut, times the feed rate the material removal rate is typically measured in cubic centimetres per minute (cm^3/min).

1.5.2 Surface Roughness

It is the measure of the finely spaced micro-irregularities on the surface texture which is composed of three components, namely roughness, waviness, and form. Surface roughness, often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

Roughness plays an important role in determining how a real object will interact with its environment. In tribology, rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities on the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion.

Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. For example, it is difficult and expensive to control surface roughness of fused deposition modelling manufactured parts. Decreasing the roughness of a surface usually increases its manufacturing cost. This often results in a trade-off between the manufacturing cost of a component and its performance in application. Roughness can be measured by manual comparison against a "surface roughness comparator" (a sample of known surface roughness), but more generally a surface profile measurement is made with a profilometer. These can be of the contact variety (typically a diamond stylus) or optical (e.g.: a white light interferometer or laser scanning confocal microscope).

1.5.3 Tool Temperature

During the cutting of metal, the temperature of the interaction area of the cutting tool and workpiece becomes high. The temperature affects not only the rate of wear of the cutting tool but also the integrity of workpiece surface such as residual stress, hardness, and surface roughness.

1.6 WORKPIECE

The work piece material used in this project was AISI 316 Stainless Steel. AISI 316 is the second most commonly available/widely used type of stainless steel after the AISI 304. Considered the generic workhorse, SS316 can serve in most situations with great success. In comparison, SS AISI 316 boasts better resistance to chloride-rich conditions than the typical SS 304 thanks to the molybdenum addition. However, while both are typically used in industry, SS AISI 316 is used in even harsher environments where there is a need for:

- Greater corrosion resistance
- Greater tensile strength at higher operating temperatures
- Acidic resistance of solutions of nitric acid of concentration as high as 5% at 50 °C
- Phosphoric acid of concentration of up to 20% at 100 °C

Iron (Fe)	68.5%
Chromium (Cr)	16.25%
Nickel (Ni)	11.5%
Molybdenum (Mo)	2.5%
Manganese (Mn)	1%
Silicon (Si)	0.5%
Nitrogen (N)	0.05%
Carbon (C)	0.04%
Phosphorus (P)	0.023%
Sulfur (S)	0.015%

Table 1.1 Composition of Workpiece

Material Density	8000 kg/m^3
Elastic Modulus	193 GPascal
Mean Thermal Expansion Coefficient	16.5 µm/m/°C
Mean Thermal Conductivity	18.9 W/m*K
Specific Heat Capacity	500 J/kg*K
Electrical Resistivity	740 (nΩ*m)
Melting Onset	1380 °C / 2510 °F
Melting Completion	1400 °C / 2550 °F
Embodied Energy	53 MJ/kg
Calomel Potential	-50 mV

Table 1.2 Physical Properties

Max Tensile Strength	580 MPascal
Yield Tensile Strength	290 MPascal
Elongation	40% (50 mm)
Elongation at break	50% (50 mm)
Rockwell Hardness	95
Brinell Hardness	219

Table 1.3 Mechanical Properties

1.7 CARBIDE TOOL

Carbide Tools and Inserts are the most widely used tools in the Machining Industry for the last few decades. But have you ever wondered What is Carbide and why have Carbide Tools become so popular? Carbide is a Chemical Compound composed of Carbon along with a less electronegative element than Carbon itself. Carbides can be broadly classified into:

- Metal Carbides: Carbon compounded with less electronegative metals like Tungsten, Titanium, Cobalt, Tantalum, or Vanadium
- Non-Metal Carbides: Carbon compounded with less electronegative non-metals like Boron, Calcium, or Silicon

Tungsten Carbide, commonly known as Carbide these days, a compound of Carbon and Tungsten has revolutionized the Machine Tool Industry over the last decades by providing increased cutting speed and feed rate with a longer tool life span as compared to their traditional counterparts.

1.7.1 History

A Scientist from the General Electric Company's Lamp Department named Dr. Samuel Leslie Hoyt was the first to investigate Tungsten Carbide as a Cutting Tool Material. Later Dr. Samuel Leslie Hoyt went on to develop Carboloy, an alloy of Tungsten, Carbide and Cobalt.

1.7.2 Advantages of Carbide Tools

- Carbide tools can be worked at higher speeds as compared to HSS tools, approximately 6 to 8 times higher speeds.
- Young's Modulus of Elasticity of Carbide tools is 3 times that of steel, making it stiff.
- Workpiece/parts machines using Carbide tools generate a surface finish of high quality.
- Carbide Tools have an exceptional resistance to abrasion.
- They have a high resistance to Catering and Thermal Deformations.
- Carbide tools have a high wear resistance, enabling the user to use the tool at higher speeds and longer durations as compared to other materials like HSS.
- Carbide tools provide a higher value for money than their steel counterparts.
- Carbide tools can machine Hardened Steel.
- Carbide tools are chemically inert.
- Torsional Strength of Carbide Tools is twice of that of HSS tools.
- Tips of Carbide Tipped tools can be easily replaced for further use.

1.7.3 Classification of Carbide Tools

Carbide Tools are classified into three major grades:

- WEAR Grade: Primarily used in dies, machine and tool guides as well as in everyday items like fishing rods, reels and wherever good wear resistance is required.
- IMPACT Grade: Particularly used in the processes of Forming and Stamping, heads of mining drill and also dies.
- CUTTING TOOL Grade: Tool grades of cemented carbides are further classified into two parts based on their primary application, Cast Iron Carbide and Steel Grade Carbide. Cast Iron Carbides are used on cast iron which is a non-ductile material, whereas Steel Grade Carbides are used to cut a ductile material of steel. Cast Iron Carbides are more resistant to abrasion wear. Steel Grade Carbides require more resistance to cratering and heat.

Fig. 1.9 Tungsten Carbide Tipped Tool (Used Tool)

1.8 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) is an analysis tool used in statistics that splits an observed aggregate variability found inside a data set into two parts: systematic factors and random factors. The systematic factors have a statistical influence on the given data set, while the random factors do not. Analysts use the ANOVA test to determine the influence that independent variables have on the dependent variable in a regression study.

The t- and z-test methods developed in the 20th century were used for statistical analysis until 1918, when Ronald Fisher created the analysis of variance method. ANOVA is also called the Fisher analysis of variance, and it is the extension of the t- and z-tests. The term became well-known in 1925, after appearing in Fisher's book, "Statistical Methods for Research Workers”. It was employed in experimental psychology and later expanded to subjects that were more complex.

1.9 MINITAB

Minitab is a statistics package. It was developed at the Pennsylvania state University by researchers Barbara F. Ryan, Thomas A. Ryan Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMINITAB, statistical analysis program by NIST. It can be used for learning about statistics as well as statistical research. Statistical analysis computer application has the advantage of being accurate, reliable and general faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals. Minitab is distributed by Minitab Inc., a privately owned company headquartered in state college, Pennsylvania with subsidiaries Coventry, England (Minitab limited), Paris, France (Minitab SARL) and Sydney, Australia (Minitab Pty.). Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics-based process improvement methods. Minitab 17, the latest version of the software, is available in 7 languages: English, French, German, Japanese, Korean, Simplified Chinese and Spanish.

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Minitab Inc. produces two other products that complement Minitab 17: Quality trainer, a learning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 17 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software and Quality companion 3, an integrated tool for managing six sigma and Lean manufacturing projects that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs, and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However, each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise, you can print projects and its elements.

1.9.1 Minitab project and Worksheets:

The Menu bar: You can open menus and choose commands. Here you can find the built-in routines.

The Toolbar: Shortcuts to some Minitab commands.

1.9.2 Two windows in Minitab:

1. Session window: The area that displays the statistical results of your data analysis and can also be used to enter commands.

2. Worksheet window: A grid of rows and columns used to enter and manipulate the data. Note: This area looks like a spreadsheet but will not automatically update the columns when entries are changed.

Other windows include,
Graph Window: When you generate graphs, each graph is opened in its own window.

Report Window: Version 17 has the report manager that helps you organize your results in a report.

Other Windows: History and project manager are other windows. See Minitab help for more information on these if needed.

1.10 DOE OVERVIEW

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the important effects. If there is an interaction between two or more input variables, they should be included in the design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable. Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

1.10.1 Planning

Careful planning helps in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of the system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Minitab provides numerous tools to evaluate process control and analyze your measurement system.

1.10.2 Screening

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

1.10.3 Optimization

After identifying the vital variables by screening, there is a need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective. The optimization methods available in Minitab include general full factorial designs (designs with more than two levels), response surface designs, and Taguchi designs.

- Factorial Designs Overview describes methods for designing and analyzing general full factorial designs.
- Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.
- Response Optimization describes methods for optimizing multiple responses. Minitab provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.
- Taguchi Designs Overview describes methods for analyzing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-outer array designs.

1.10.4 Verification

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

1.11 RESPONSE SURFACE METHODOLOGY

Response Surface Methodology, RSM (also known as Response Surface Modeling) is a technique to optimize the response(s) when two or more quantitative factors are involved. The dependent variables are known as responses, and the independent variables or factors are primarily known as the predictor variables in response surface methodology. While p-values are used for a particular point such as to test the hypothesis of “whether the 70-degree Fahrenheit is the most comfortable temperature or not,” the response surface is useful in determining a range of temperatures for the same comfort level. As maintaining the temperature exactly at a 70-degree could be very expensive, maintaining the temperatures within a range is often desired for a cost-effective solution. Moreover, keeping very cool in summer or very hot in winter would be very wasteful. Response Surface Methodology, RSM, is very useful to optimize variables/factors more practically as compared to just the statistical significance test for a particular point (point estimate is the statistical jargon).

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

Balla Srinivasa Prasad, D. S. Sai Ravi Kiran [1] has done experimental investigation to optimize tool performance in high-speed drilling. The influence of drilling parameters on circularity error, tool tip temperature and flank wear were investigated while drilling of Ti–6Al–4V alloy specimens with dissimilar cutting tool materials under dry machining conditions. From the GRA analysis, they discovered that cutting tool material, rotational speed of the spindle and feed rate are big issues which disturb the drilling of difficult to cut material like Ti–6Al–4V alloy. They concluded that, Drill bit material influences (DM = 73.67%) more, followed by rotational speed (N = 16.87%) and feed rate (f = 7.86%). The best performance features were attained with TiN-coated tungsten carbide twist drill bit when drilling with higher feed of 400 mm/min and higher rotational speed of 10,600 rpm at constant cutting point angle.

C.K. Akhil, C.S. Akhil, M. H. Ananthavishnu, P.M. Afeez, R. Akhilesh, Rahul Rajan [2] conducted various experiments and concluded that if the depth of cut increases, the section of chip increases and friction of chip-tool increases which leads to an increase in temperature. The maximum temperature developed in the cutting tool tip during machining was found to be 141.5oC. The optimum condition for obtaining maximum surface finish, with least rise in temperature at tool tip, is high cutting speed (RPM) with low depth of cut and medium feed rate. The optimum condition for least machining time and least rises in temperature at tool tip is medium cutting speed with medium depth of cut and high feed rate. By carrying out proper measuring and applying suitable methods to reduce the developed temperature during machining operation can improve the quality of the work piece and can enhance the life of the cutting tool.

R.B. Kakade, S.B. Chikalthankar, V.M. Nandedkar [3] conducted an experiment which evaluates the tool tip temperature in Turning of OHNS with carbide cutting tool. The Taguchi method was very useful in analyzing the optimum condition of parameters and significance of individual parameters to tool tip temperature. In case of tool tip temperature, it has been observed that the depth of cut was the most influencing parameter followed by spindle speed and feed. In order to obtain minimum temperature in case of OHNS within work interval considered in this study, one should use low values of depth of cut and spindle speed.

Naveen Kumar, Sidharth Mishra, Sumit Mishra [4] has done analysis on metal removal rate in turning of AISI 304 stainless steel. It can be observed from S/N Ratio plot that maximum Metal Removal Rate is obtained when the cutting parameters are set as DOC is 1.2 mm at 700 RPM with constant feed of 30 teeth per inch which can be considered optimum settings to improve metal cutting through turning this workpiece with the tool used in this particular Lathe Machine. Furthermore, ANOVA analysis is done to find out the effect of each cutting parameters upon MRR and it is observed from ANOVA response table that RPM contributes to 85.05% and DOC 8.94% towards MRR upon constant feed of 30 teeth per inch hence it can be said that RPM is major factor in this turning operation on AISI 304 stainless steel.

A.A. Latif, A.Z. Amran, E.A. Rahim, M.R. Ibrahim [5] studied on the effect of feed rate and cutting speed on surface roughness and material removal rate of mild steel. This paper provides an insight to the effect of feed rate and cutting speed on NOVIANO and conventional cutting tool in term of surface roughness and Material Removal Rate (MRR). The output of the machining during slot milling of Mild Steel with 17 HRC were measured. Mitutoyo surface tester were used to measure average mean surface roughness (Ra) of the slot milling surface. For the MRR measurement, mathematical formula was used to calculate and evaluate the different weight of workpiece before and after milling. The result shows that, when the feed rate and cutting speed increase, better surface roughness and MRR will be occur. However, the comparison between both cutting tools found that the NOVIANO cutting tool produce much better result than conventional cutting tool where surface roughness and MRR is 13.97% and 51.62%.

Kai-Chi Chuang, Tian-Syung Lan, Yee-Ming Chen [6] has optimized machining parameters using Fuzzy Taguchi Method for Reducing Tool Wear. This study investigates the optimal machining parameters for the computer numerical controlled turning process of S45C steel in minimizing tool wear. The correlation between control parameters (speed, cutting depth, and feed rate) and production quality were constructed by using semantic rules and fuzzy quantification. The Taguchi method was additionally employed to determine the optimal turning parameters. Under the consideration of environmental protection and tool cost, the optimal machining parameters were furthermore derived from the fuzzy semantic rules. The practicability of the optimal parameters was moreover verified through turning experiments.

N. Baskar, S. Bharathi Raja [7] has used Particle swarm optimization technique for determining optimal machining parameters of different work piece materials in turning operation. PSO has been used to find the optimal machining parameters for minimizing machining time subjected to desired surface roughness. Physical constraints for both experiment and theoretical approach are cutting speed, feed, depth of cut, and surface roughness. It is observed that the machining time and surface roughness based on PSO are nearly same as that of the values obtained based on confirmation experiments; hence, it is found that PSO is capable of selecting appropriate machining parameters for turning operation.

Gaurav Soni, Raman Kumar, Saurabh Chhabra [8] made an attempt to analysis the effects of input parameters such as speed, feed, depth of cut and nose radius on output parameter such as material removal, surface roughness and time. Literature reveals that different MADM approach may provide different ranking to alternates for same problem. Thus, to minimize the error while ranking alternates a VIKOR method has been used to rank out the alternatives and compared the result with existing result computed with TOPSIS method. In this work four input parameters such as speed, feed, D.O.C, nose radius has been considered and influence of input parameters has been investigated. The results shown that speed 1500rpm, feed, D.O.C 1mm and nose radius at 1.2 is the appropriate best input parameters setting.

D. Vijay Kumar, J. Chandrashekar, Mahipal Manda [9] has given the best condition for cutting speed factor is level 3 (96.6 m/min) (1025 rpm), for feed is level 2 (150 mm/rev), for depth of cut is level 2 (0.8mm), straight cutting oil in cutting fluids in level 3 for work piece material AISI stainless steel. The graphs show the main effect plot for S/N ratios. It is clear that the S/N ratio is larger at cutting fluid, straight cutting oil. Then we can say that the optimum cutting fluid is straight cutting oil. It means that the values we got by using straight cutting oil are optimum values.

Ahilan Chandrakasan, N. Sivakumaran, Somasundaram Kumanan [10] used Grey based fuzzy logic approach in optimization of CNC turning process with multiple performance characteristics. This approach integrates both grey relational analysis and fuzzy logic for optimizing the complicated multiple performance characteristics. This approach converts the optimization of multiple performance characteristics in to a single grey-fuzzy reasoning grade. Optimum level of parameters has been identified based on grey-fuzzy reasoning grade. In this study, CNC turning parameters namely cutting speed, feed rate, depth of cut and nose radius are optimized with consideration of performance characteristics such as surface roughness and power consumption. The significant contributions of parameters are estimated using Analysis of Variance (ANOVA).

Neeraj, Sukhdeep S. Dhami [11] performed studies on process parameters such as spindle speed, feed, depth of cut, environment, nose radius, and the impact on surface roughness, material removal rate, power consumption, tool wear rate, and thrust force. This work consists of an analysis of the work carried out by the researchers in the field of filming process parameters, to Examine the impact of speed, cutting speed (feed), and depth of cut in a computer numeric control machine. This study will provide insight into current trends research in the area of Taguchi, Grey Relational Analysis, Response Surface Method, ANOVA & CNC Turning.

Karnal Renu Sharma, Neeraj Sharma [12] applied extended Taguchi method through a case study in straight turning of mild steel bar using HSS tool for the optimization of process param. The study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality as well as productivity with special emphasis on reduction of cutting tool flank wear, because reduction in flank wear ensures increase in tool life. The predicted optimal setting ensured minimization of surface roughness. From the present research of ANOVA, it is found the Depth of cut is most significant, spindle speed is significant and feed rate is least significant factor effecting surface roughness.

Sanchit Kumar Kharea, Sanjay Agarwal [13] has done research on cryogenic turning process involves the modelling and optimization of the process parameters affecting the machining performance and value oriented sustainable manufacturing. The machining parameters namely the cutting speed, feed rate, depth of cut and rake angle are optimized for minimum surface roughness on AISI 4340 steel. The experimentation was planned using Taguchi’s L9 theory. An orthogonal array (L9), the signal-to-noise (S/N) ratio was employed to the study the surface roughness in the turning of AISI 4340 steel under cryogenic condition. It was observed that cutting speed and depth of cut was the most influential factors on the surface roughness.

Ashvin, J. Makadia, J.I. Nanavati [14] studied the effect of the main turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on the surface roughness of AISI 410 steel. A mathematical prediction model of the surface roughness has been developed in the terms of above parameters. The effect of these parameters on the surface roughness has been investigated by using Response Surface Methodology (RSM). Response surface contours were constructed for determining the optimum conditions for a required surface roughness. The result shows that the feed rate is the main influencing factor on the roughness, followed by the tool nose radius and cutting speed, roughness has been investigated by using Response Surface Methodology (RSM).

Kali Dass, S.R. Chauhan [15] studied the performance of polycrystalline diamond (PCD) cutting insert during turning of titanium (Grade-5) alloy using response surface methodology (RSM). The result shows that the surface roughness increases with increase in the cutting speed and the feed rate decreases with decrease in approach angle and depth of cut. The tangential force increases with increase in approach angle and depth of cut, and decreases with decrease in cutting speed and feed rate.

P. Sahoo [16] conducted an experimental study of roughness characteristics of surface profile generated in CNC turning of AISI 1040 mild steel and optimization of machining parameters based on genetic algorithm. It is seen that the surface roughness parameters decrease with increase in depth of cut and spindle speed but increase with increase in feed rate.

I. Ramu, K. Venkatesh, P. Srinivas [17] focuses on optimization of turning parameters using the Taguchi technique to minimize surface roughness and maximize material removal rate. The experimental investigation for turning operations has been executed on a CNC lathe. Turning operations are performed based on the orthogonal array with L9 for stainless steel (316). The experimental results were analyzed using ANOVA approach. The optimal condition for both material removal rate and surface roughness are calculated by using a technique called grey relational analysis. Grey relation grade is used to calculate the optimal condition for combined parameters.

Franko Puh, Miran Brezocnik, Mladen Perinic, Stipo Buljan, Zoran Jurkovic [18] investigated multi-objective optimization of turning process for an optimal parametric combination to provide the minimum surface roughness (Ra) with the maximum material-removal rate (MRR) using the Grey–Based Taguchi method. Turning parameters considered were cutting speed, feed rate and depth of cut. Nine experimental runs based on Taguchi’s L9 (3^4) orthogonal array were performed followed by the Grey relational analysis. Based on the Grey relational grade value, optimum levels of parameters were identified. The significance of parameters on overall quality characteristics of the cutting process evaluated by the analysis of variance (ANOVA). The optimal parameter values obtained during the study was validated by confirmation experiment.

N. Muthu Krishnan, Ramanujam, R. Raju [19] had done the detailed experimental investigation on turning Aluminum silicon Carbide particulate Metal Matrix Composite (Al-SiC –MMC) using polycrystalline diamond (PCD) fine grade insert.

Experiments were carried out on a medium duty lathe. Analysis of variance (ANOVA) is used to investigate the machining characteristics of MMC (A356/10/SiCP). The objective was to establish a correlation between cutting speed, feed and depth of cut with the specific power and surface finish on the work piece. The optimum machining parameters were obtained by using grey relational analysis for minimum power consumption and better surface finish.

K. S. Vepa, Malleswari Karanam, Mulugundam Siva Surya [20] had done optimization on turning of Aluminum 7075 with High-speed steel and concluded from the response table of the Grey relational analysis, speed is the strongest factor among the other parameters used on the multi performance characteristics. The percentage contribution of cutting speed at stage 1 (325 RPM) is ranked one because of its high influence over material removal rate, tool wear and surface roughness. The maximum material removal rate, minimum tool wear and surface roughness are selected as the quality targets.

CHAPTER 3

EQUIPMENT DETAILS AND DESIGN OF EXPERIMENTS

CHAPTER 3

EQUIPMENT DETAILS AND DESIGN OF EXPERIMENTS

3.1 WORKPIECE

The work piece material used for experiments is AISI 316 Stainless Steel of 32 X 50mm.

Fig. 3.1 Workpiece 1 before machining

Fig. 3.2 Workpiece 2 before machining

Two workpieces are taken to conduct a total of 9 experiments. Each experiment sample machining length is 50mm. The machining parameters change for each experiment resulting in different MRR, surface roughness, tool temperature values.

3.2 CUTTING TOOL

The tool used for machining is TUNGSTEN CARBIDE tipped tool.

Fig. 3.3 Tungsten Carbide Tool

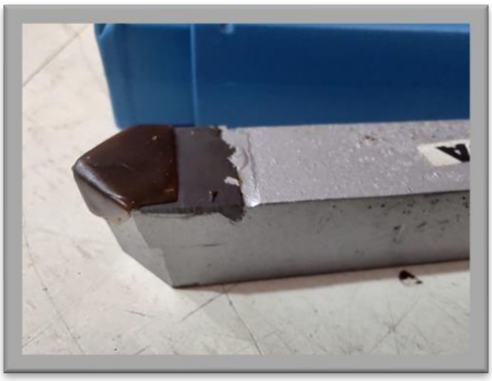

Fig. 3.4 Tungsten Carbide Tool (with cap)

3.3 TAGUCHI METHOD

Taguchi Methods are statistical methods, or sometimes called as the robust design methods, developed by Genichi Taguchi to improve the quality of manufactured goods. It is a method to design an experiment, as it creates the set of arrays with variable factors arranged in such a way that only significant variation is pointed out and rest of insignificant set of variables are neglected thus reducing the no. of experiment.

3.3.1 Parameters Setting

Level	**Spindle Speed**	**Feed Rate**	**Depth of Cut**
1	835	0.45	0.25
2	1330	0.75	0.5
3	2000	1	0.75

Table 3.1

3.3.2 Taguchi Design Summary

Taguchi Array	**L9(3^3)**
Factors	3
Runs	9

Table 3.2

3.3.3 L9(3^4) Array of Influencing Parameter and Their Levels

Expt. No.	**Spindle Speed (RPM)**	**Feed Rate (mm/rev)**	**DEPTH OF CUT (mm)**
1	835	0.45	0.25
2	835	0.75	0.50
3	835	1	0.75
4	1330	0.45	0.50
5	1330	0.75	0.75
6	1330	1	0.25
7	2000	0.45	0.75
8	2000	0.75	0.25
9	2000	1	0.50

Table 3.3

CHAPTER 4

EXPERIMENTATION

CHAPTER 4

EXPERIMENTATION

4.1 EXPERIMENTAL SETUP

A center lathe was used to carry out the machining. The insert was clamped in a holder and mounted on the tool post. The job was held rigidly by the chuck of the lathe. Centre drilling was done and the job was held at the other end by the tail stock and a skin pass was carried out. The setup was hence complete and the runs could be carried out from here.

Fig. 4.1 Centre Lathe with digital weighing machine

Fig. 4.2 Workpiece in position for center drilling

Fig. 4.3 Workpiece in position for machining

4.2 MATERIAL REMOVAL RATE CALCULATION

In order to calculate metal removal rate first, the initial weight of each AISI 316 SS bar is taken from weighing device. Spindle Speed, Feed Rate and Depth of Cut are selected as per the Taguchi’s L9 orthogonal array. Machining operation is performed on specific length of material (50mm). Machining time is obtained from the formula.

Machining time (in seconds) = (Machining length/ (Spindle Speed*feed)) *60

After machining, final weight of each test bar is determined from weighing device. Finally, MRR is calculated by using formula,

MRR (mm3/sec) = (Initial Weight – Final Weight) / (Density * Machining time)

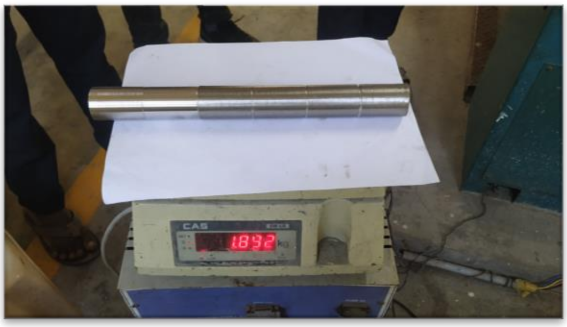

Fig. 4.4 Checking workpiece weight before machining

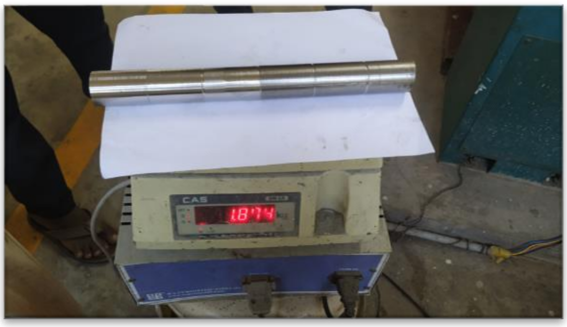

Fig. 4.5 Checking workpiece weight after machining

4.3 SURFACE ROUGHNESS MEASUREMENT

Surface Roughness of the machined surfaces is calculated using Talysurf Surface Roughness Tester. Talysurf is used to measure the surface roughness by using an electronic principle, this surface meter consists of stylus and skid type instrument used for measuring the surface of the give product.

In this instrument, the stylus points out the profile of the surface and any deflections of a stylus is converted into electric current to identify the measurements of the object.

Fig. 4.6 Talysurf Surface Roughness Tester

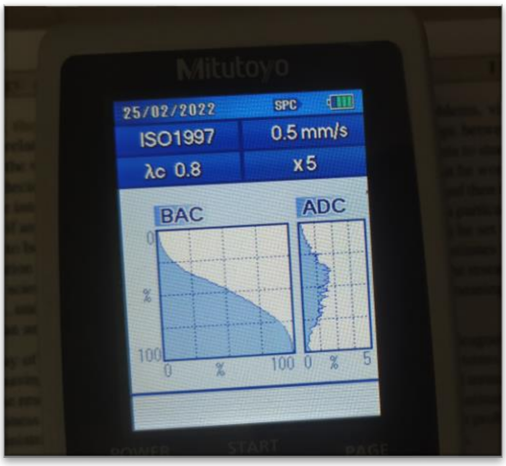

Fig. 4.7 Tester Specifications

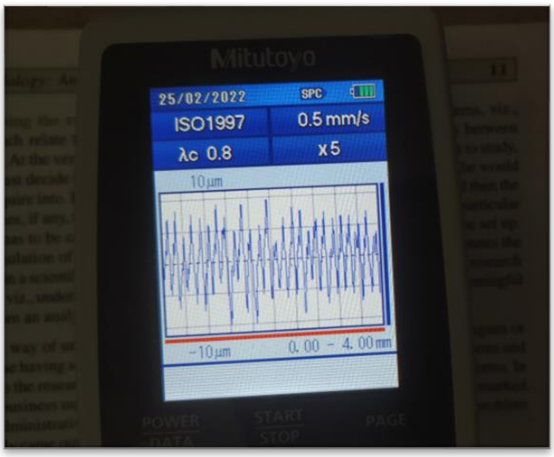

Fig.4.8 Measuring surface roughness

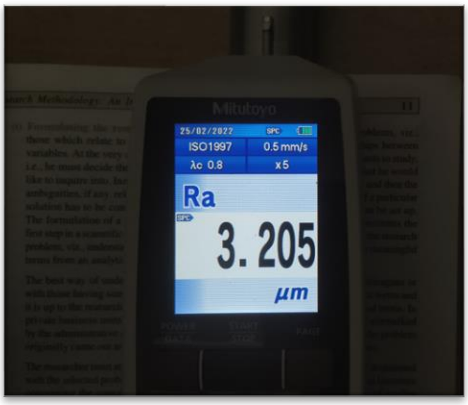

Fig 4.9 Tester displaying Ra value

Fig 4.10 Tester displaying Rq value

Fig 4.11 Tester displaying Rz value

λc 0.8 mm
λs 2.5 µm
N 5
M-Speed 0.5 mm/s
Range AUTO

Fig 4.12 Checking pre-specified values on tester

4.4 TOOL TIP TEMPERATURE MEASUREMENT

Tool temperature is observed using IR thermometer. Infrared (IR) thermometers enable you to measure temperature quickly, at a distance, and without touching the object you're measuring. An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called black-body radiation emitted by the object being measured.

Fig. 4.13

Fig. 4.14

Fig. 4.15

- Fig. 4.13, 4.14, 4.15 shows the tool tip temperature measurement for various experiments

CHAPTER 5

RESULTS AND DISCUSSIONS

CHAPTER 5

RESULTS AND DISCUSSIONS

In this chapter the experimental results of Material Removal Rate (MRR), Surface Roughness (R_a, R_q, R_z) and Tool Temperature are analyzed using ANOVA method. Mathematical models and Residual plots are obtained for all the response factors. The focus of the work is to identify the optimal combination of process parameters that concurrently maximizes the material removal rate and minimizes the surface roughness and tool temperature.

5.1 INITIAL OBSERVATIONS

Expt No	**Spindle Speed (RPM)**	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**	**Initial Weight (grams)**	**Final Weight (grams)**	**Machining Time (sec)**	**Tool Temperature (°C)**
1	835	0.45	0.25	1912	1906	7.9840319	55
2	835	0.75	0.5	1906	1892	4.7904191	67
3	835	1	0.75	1892	1874	3.5928143	112
4	1330	0.45	0.5	1874	1860	5.0125313	47
5	1330	0.75	0.75	1860	1831	3.0075187	102
6	1330	1	0.25	1959	1955	2.255639	66
7	2000	0.45	0.75	1935	1912	3.333333	177
8	2000	0.75	0.25	1955	1949	2	82
9	2000	1	0.5	1949	1935	1.5	76

Table 5.1 Observations Table

5.2 EXPERIMENTAL RESULTS

Expt No.	Spindle Speed (RPM)	Feed Rate (mm/ rev)	Depth Of Cut (mm)	MRR (mm^3/ sec)	R_a (µm)	R_q (µm)	R_z (µm)	Tool Temperature (°C)
1	835	0.45	0.25	94.05	3.16	3.75	15.56	55
2	835	0.75	0.5	365.76	3.42	4.11	16.37	67
3	835	1	0.75	627.03	4.26	5.21	22.58	112
4	1330	0.45	0.5	349.56	2.71	3.266	12.64	47
5	1330	0.75	0.75	1206.8	9.13	10.77	39.46	102
6	1330	1	0.25	221.94	20.08	23.51	83.08	66
7	2000	0.45	0.75	863.57	4.42	5.20	20.54	177
8	2000	0.75	0.25	375.46	14.87	18.64	76.16	82
9	2000	1	0.5	1168.1	13.94	16.67	61.11	76

Table 5.2 Results of Output Parameters

5.3 ANOVA Analysis of MRR

Source	DF	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed	1	290528	290528	2.28	0.270	21.905
Feed Rate	1	83991	83991	0.66	0.502	6.33
Depth of Cut	1	670639	670639	5.26	0.149	50.56
Spindle Speed*Spindle Speed	1	3755	3755	0.03	0.879	0.28
Feed Rate*Feed Rate	1	14256	14256	0.11	0.770	1.07
Depth of Cut*Depth of Cut	1	7938	7938	0.06	0.826	0.59
Error	2	254776	127388			19.21
Total	8	1326252				100

Table 5.3 Analysis of Variance for MRR

ANOVA results of the responses for MRR were given in table 5.3 respectively. From the results it is observed that depth of cut and spindle speed are the most significant factor for the responses respectively.

5.4 Mathematical Model and Residual Plots for MRR

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyze the distribution of errors. From the normality (fig 5.1) and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

5.4.1 Regression Equation for MRR

MRR = -1902+ 0.75 Spindle Speed+ 2065 Feed Rate
+ 2345 Depth of Cut- 0.000131 Spindle Speed*Spindle Speed
- 1127 Feed Rate*Feed Rate
- 1008 Depth of Cut*Depth of Cut

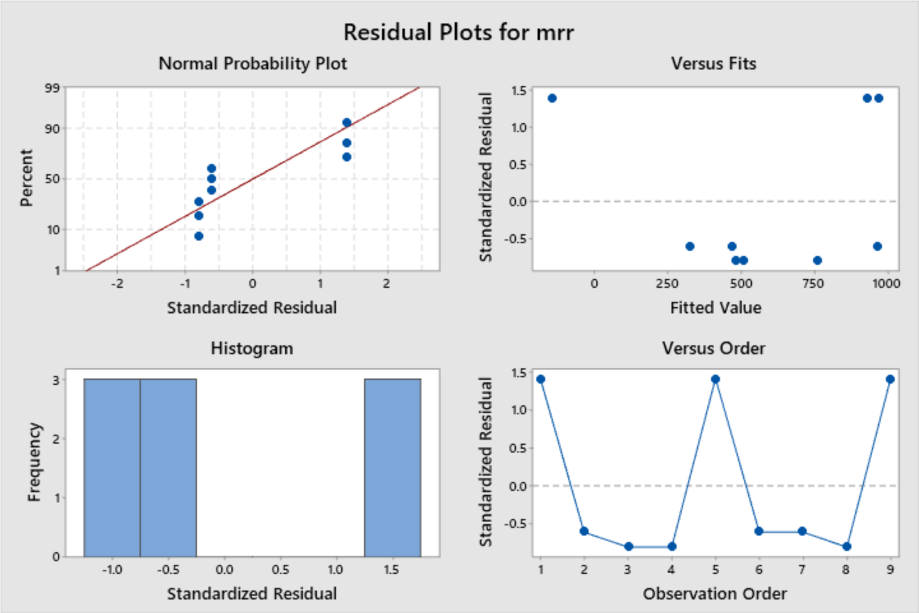

Fig 5.1 Residual plots for MRR

5.5 ANOVA Analysis of R_a

Source	DF	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed	1	83.562	83.562	25.54	0.037	25.54
Feed Rate	1	130.632	130.632	39.93	0.024	39.94
Depth of Cut	1	68.653	68.653	20.98	0.045	20.98
Spindle Speed*Spindle Speed	1	29.518	29.518	9.02	0.095	9.02
Feed Rate*Feed Rate	1	0.772	0.772	0.24	0.675	0.23
Depth of Cut*Depth of Cut	1	13.819	13.819	4.22	0.176	4.22
Error	2	6.544	3.272			2.00
Total	8	327.121				100

Table 5.4 Analysis of Variance for R_a

ANOVA results of the responses for R_a were given in table 5.4 respectively. From the results it is observed that feed rate and spindle speed are the most significant factor for the responses respectively.

5.6 Mathematical Model and Residual Plots for R_a

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyze the distribution of errors. From the normality (fig 5.2) and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

5.6.1 Regression Equation for R_a

Ra = -22.0 + 0.0394 Spindle Speed + 29.0 Feed Rate - 55.6 Depth of Cut
- 0.000012 Spindle Speed*Spindle Speed - 8.3 Feed Rate*Feed Rate
+ 42.1 Depth of Cut*Depth of Cut

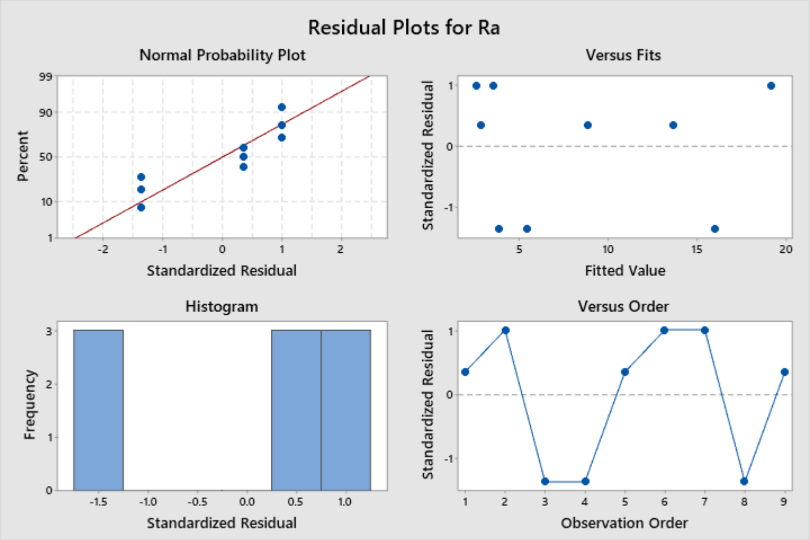

Fig 5.2 Residual plots for R_a

5.7 ANOVA Analysis of R_q

Source	DF	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed	1	125.496	125.496	43.68	0.022	26.85
Feed Rate	1	183.460	183.460	63.86	0.015	39.26
Depth of Cut	1	101.863	101.863	35.45	0.027	21.79
Spindle Speed*Spindle Speed	1	36.236	36.236	12.61	0.071	7.75
Feed Rate*Feed Rate	1	2.281	2.281	0.79	0.467	0.48
Depth of Cut*Depth of Cut	1	20.069	20.069	6.99	0.118	4.29
Error	2	5.746	2.873			1.22
Total	8	467.288				100

Table 5.5 Analysis of Variance for R_q

ANOVA results of the responses for R_q were given in table 5.5 respectively. From the results it is observed that feed rate and spindle speed are the most significant factor for the responses respectively.

5.8 Mathematical Model and Residual Plots for R_q

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyze the distribution of errors. From the normality (fig 5.3) and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

5.8.1 Regression Equation for R_q

Rq = -26.4 + 0.0444 Spindle Speed + 40.8 Feed Rate - 67.2 Depth of Cut
- 0.000013 Spindle Speed*Spindle Speed - 14.3 Feed Rate*Feed Rate
+ 50.7 Depth of Cut*Depth of Cut

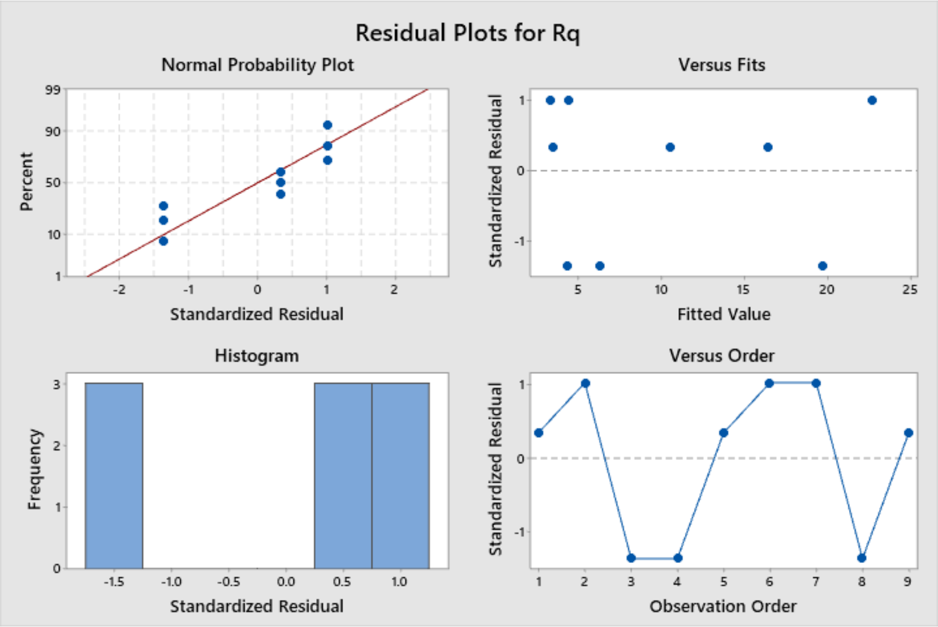

Fig 5.3 Residual plots for R_q

5.9 ANOVA Analysis of R_z

Source	DF	Adj SS	Adj MS	F	P	% Contribution
Spindle Speed	1	1778.55	1778.55	286.09	0.003	28.78
Feed Rate	1	2322.04	2322.04	373.51	0.003	37.58
Depth of Cut	1	1417.18	1417.18	227.96	0.004	22.93
Spindle Speed*Spindle Speed	1	298.36	298.36	47.99	0.020	4.82
Feed Rate*Feed Rate	1	78.83	78.83	12.68	0.071	1.27
Depth of Cut*Depth of Cut	1	330.67	330.67	53.19	0.018	5.35
Error	2	12.43	6.22			0.20
Total	8	6178.45				100

Table 5.6 Analysis of Variance for R_z

ANOVA results of the responses for R_z were given in table 5.6 respectively. From the results it is observed that spindle speed and feed rate are the most significant factor for the responses respectively.

5.10 Mathematical Model and Residual Plots for R_z

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyze the distribution of errors. From the normality (fig 5.4) and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

5.10.1 Regression Equation for R_z

Rz = -86.9+ 0.1344 Spindle Speed+ 193.1 Feed Rate- 267.2 Depth of Cut
- 0.000037 Spindle Speed*Spindle Speed- 83.8 Feed Rate*Feed Rate
+ 205.7 Depth of Cut*Depth of Cut

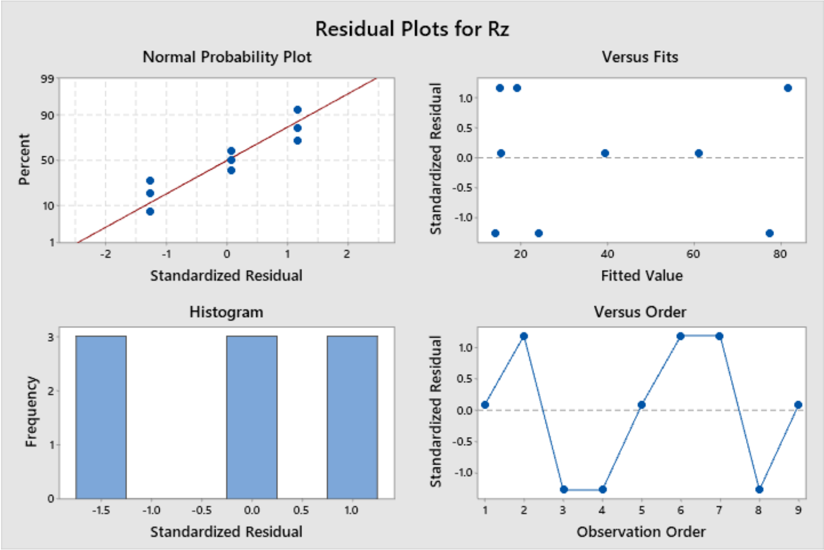

Fig 5.4 Residual plots for R_z

5.11 ANOVA Analysis of Tool Temperature

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
Spindle Speed	1	1700.2	1700.17	2.85	0.234	13.53
Feed Rate	1	104.2	104.17	0.17	0.717	0.82
Depth of Cut	1	5890.7	5890.67	9.86	0.088	46.89
Spindle Speed*Spindle Speed	1	845.5	845.50	1.42	0.356	6.73
Feed Rate*Feed Rate	1	45.7	45.72	0.08	0.808	0.36
Depth of Cut*Depth of Cut	1	2544.2	2544.22	4.26	0.175	20.25
Error	2	1194.9	597.44			9.51
Total	8	12560.9				100

Table 5.7 Analysis of Variance for Tool Temperature

ANOVA results of the responses for Tool Temperature were given in table 5.7 respectively. From the results it is observed that depth of cut is the significant factor among others for the responses respectively.

5.12 Mathematical Model and Residual Plots for Tool Temperature

Regression analysis has been conducted to prepare models for the responses. The residual plots were drawn to analyze the distribution of errors. From the normality (fig 5.5) and versus fits and order plots for responses, it is concluded that the residuals are not following normality and they are not showing any regular pattern hence the models developed are accurate and adequate.

5.12.1 Regression Equation for Tool Temperature

TT = 255- 0.148 Spindle Speed- 108 Feed Rate- 445 Depth of Cut
+ 0.000062 Spindle Speed*Spindle Speed + 64 Feed Rate*Feed Rate
+ 571 Depth of Cut*Depth of Cut

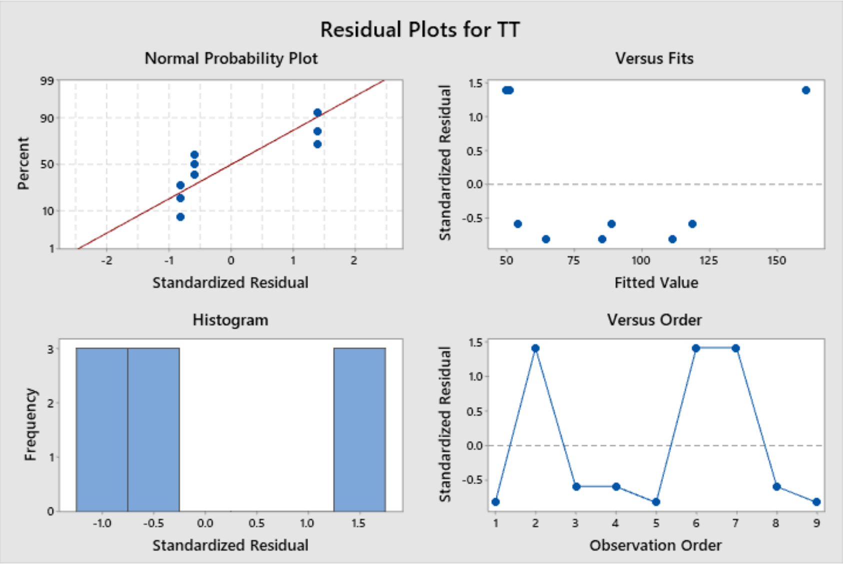

Fig 5.5 Residual plots for Tool Temperature

5.13 RESPONSE SURFACE OPTIMIZATION

Response Optimization for all output parameters is achieved by fixing goals (either minimum or maximum) to each output parameter. Minitab is used to run the Response Surface Optimization technique. Table 5.8 shows the considered parameters to run the optimization technique. Later, the optimal input parameters are displayed in the minitab and are shown below (Table 5.9)

Response	**Goal**	**Lower**	**Target**	**Upper**	**Weight**	**Importance**
TT	Minimum		47.00	177.000	1	1
R_z	Minimum		12.64	83.085	1	1
R_q	Minimum		3.27	23.513	1	1
R_a	Minimum		2.72	20.083	1	1
MRR	Maximum	94.05	1206.80		1	1

Table 5.8 Inputs to obtain Optimized values

Variable	**Setting**
Spindle Speed	1112.69
Feed Rate	0.561111
Depth of Cut	0.613636

Table 5.9 Optimum Conditions

The optimal output values obtained by using optimized input parameters are displayed in minitab in the form of a graph as shown below.

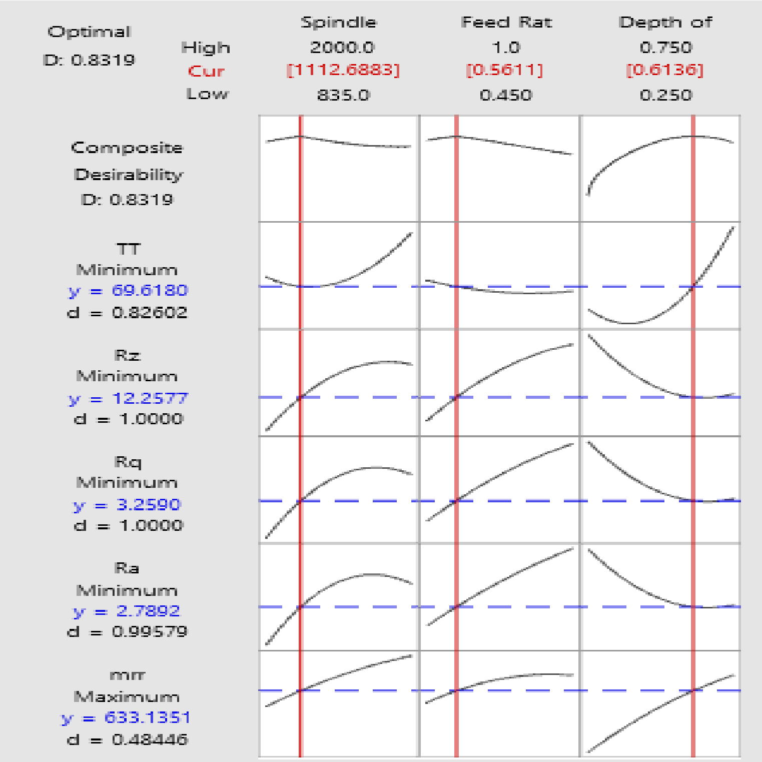

Fig 5.6 Optimization Plot

5.14 RESULTS OF CONFIRMATION EXPERIMENT

The purpose of this confirmation experiment is to verify the improvement in the quality characteristics. The optimal values of output parameters for the obtained optimum conditions (from table 5.9) are made to compare with the experimental results which were obtained by conducting the experiment with the optimal machining parameters.

Level	Optimal Result	Experiment Result	% Error
MRR	633.1351	633.5586	0.06
R_a	2.7892	2.3765	-14.79
R_q	3.2590	3.1540	-3.22
R_z	12.2577	12.2951	0.30
Tool Temperature	69.9180	68.5656	-1.93

Table 5.10 Confirmation Experiment Results

The percentage of error between the optimal and experimental values of multiple performance characteristics during the confirmation experiments is almost within 5%. So, we can say that improvement in quality characteristics has been verifies by confirmation experiment.

CHAPTER 6
CONCLUSIONS

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CONCLUSIONS

The conclusions arrived at the end of this work are as follows:

1. From this analysis, it is revealed that depth of cut is the most influencing factor for Material Removal Rate and Tool Temperature (50.56% and 46.89% respectively).

2. And also, Feed Rate is the most influencing factor for Surface Finish (39.94%, 39.26%, 37.58% are contributions for R_a, R_q, R_z respectively).

3. The Regression models prepared for all the responses showed good agreement with the experimental results as they followed normality and constant variance hence the models prepared can be used effectively for the future prediction of responses.

4. The percentage error between the optimal and experimental values of the multiple performance characteristics during the confirmation experiments is almost within 5%.

5. The value of multiple performance characteristics obtained from confirmation experiment is within the 95% confidence interval of the optimum condition.

CHAPTER 7
REFERENCES

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[1]. Balla Srinivasa Prasad, D. S. Sai Ravi Kiran, “Experimental investigation to optimize tool performance in high-speed drilling: a comparative study”, Journal of the Brazilian Society of Mechanical Sciences and Engineering (2019) 41:535.

[2]. C.K. Akhil, C.S. Akhil, M.H. Ananthavishnu, P.M. Afeez, R. Akhilesh, Rahul Rajan, “Measurement of Cutting Temperature during Machining”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 13, Issue 2 Ver. I (Mar. - Apr. 2016), PP 108-122.

[3]. R.B. Kakade, S.B. Chikalthankar, V.M. Nandedkar, “Investigation and Optimization of Tool Tip Temperature in Turning of OHNS”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 10, October- 2014.

[4]. Naveen Kumar, Sidharth Mishra, Sumit Mishra, “Analysis and Optimization of metal removal rate in turning of AISI 304 stainless steel by using Taguchi and ANOVA Methodology”, National Conference on “Sustainable and Recent Innovation in Science & Engineering-2019”.

[5]. A.A. Latif, A.Z. Amran, and E.A. Rahim, M.R. Ibrahim, “A study on the effect of feed rate and cutting speed on surface roughness and material removal rate of mild steel”, IOP Conf. Series: Materials Science and Engineering 257 (2017) 012025 doi:10.1088/1757-899X/257/1/012025.

[6]. Kai-Chi Chuang, Tian-Syung Lan, Yee-Ming Chen, “Optimization of Machining Parameters Using Fuzzy Taguchi Method for Reducing Tool Wear”, Department of Industrial Engineering and Management, Yuan Ze University, Taoyuan City 32003, Taiwan.

[7]. N. Baskar, S. Bharathi Raja, “Particle swarm optimization technique for determining optimal machining parameters of different work piece materials in turning operation”, Int J Adv Manufacturing Technology (2011) 54:445–463, DOI 10.1007/s00170-010-2958-y.

[8]. Gaurav Soni, Raman Kumar, Saurabh Chhabra, “Optimization of Process Parameters During CNC Turning by Using AHP & VIKOR Method”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 2 Issue 12, December – 2013.

[9]. D. Vijay Kumar, J. Chandra Shekar, Mahipal Manda, “Optimization of Cutting Parameters for Turning AISI 316 Stainless Steel Based on Taguchi Method”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 14, Issue 1 Ver. I (Jan. - Feb. 2017), PP 01-09.

[10]. Ahilan Chandrakasan, N. Sivakumaran, Somasundaram Kumanan, “Multiple Objective Optimization of CNC Turning Process using Grey Based Taguchi Method”, Competitive Manufacturing - Proc. of the 2nd Intl. & 23rd AIMTDR Conf. 2008.

[11]. Neeraj, Sukhdeep S. Dhami, “Review on optimization of CNC Turning Process Parameters for Surface Roughness and Material Removal Rate Using Taguchi, GRA, and RSM Approaches”, Journal of University of Shanghai for Science and Technology ISSN: 1007-6735.

[12]. Renu Sharma, Neeraj Sharma, “Optimization of Process Parameters of Turning Parts: A Taguchi Approach”, Journal of Engineering, Computers & Applied Sciences (JEC&AS) ISSN No: 2319-5606 Volume 1, No.1, October 2012.

[13]. Sanchit Kumar Kharea, Sanjay Agarwal, “Optimization of Machining Parameters in Turning of AISI 4340 Steel under Cryogenic Condition Using Taguchi Technique”, Procedia CIRP 63 (2017) 610 – 614 ScienceDirect, The 50th CIRP Conference on Manufacturing Systems.

[14]. Ashvin J. Makadia, J.I. Nanavati, “Optimisation of machining parameters for turning operations based on response surface methodology”, Measurement 46 (2013) 1521–1529. (Journal homepage: www.elsevier.com/ locate/measurement).

[15]. Kali Dass, S. R. Chauhan, “Optimization of Machining Parameters in Turning of Titanium (Grade5) Alloy Using Response Surface Methodology”, Materials and Manufacturing Processes, 27: 531–537, 2012, ISSN: 1042-6914 print/1532-2475 online, DOI: 10.1080/10426914.2011.593236.

[16]. P. Sahoo, “Optimization of Turning Parameters for Surface Roughness Using RSM And GA”, Advances in Production Engineering & Management 6 (2011) 3, 197-208 ISSN 1854-6250.

[17]. I. Ramu, K. Venkatesh, P. Srinivas, “Taguchi based grey relational analysis for optimization of machining parameters of CNC turning steel 316”, IOP Conf. Series: Materials Science and Engineering 377 (2018) 012078 doi:10.1088/1757-899X/377/1/012078.

[18]. Franko Puh, Miran Brezocnik, Mladen Perinic, Stipo Buljan, Zoran Jurkovic, “Optimization of Machining Parameters for Turning Operation with Multiple Quality Characteristics Using Grey Relational Analysis”, ISSN 1330-3651 (Print), ISSN 1848-6339 (Online), Doi: 10.17559/Tv-20150526131717.

[19]. N. Muthu Krishnan, R. Ramanujam, R. Raju, “Optimization of Machining Parameters for Turning Al-Sic (10p) MMC Using Taguchi Grey Relational Analysis”, International Journal of Industrial Engineering, 18(11), 582-590, 2011.

[20]. K. S. Vepa, Malleswari Karanam, Mulugundam Siva Surya, “Optimization of Machining Parameters using ANOVA and Grey Relational Analysis while Turning Aluminium 7075”, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-2, July 2019.