Process design and optimization of end milling parameters of Al 7075 metal matrix composite.

A Project report submitted in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

Submitted by

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CERTIFICATE

This is to certify that the Project Report entitled **"PROCESS DESIGN AND OPTIMIZATION OF END MILLING PARAMETERS OF AL7075 METAL MATRIX COMPOSITE"** being submitted by ALAVILLI SAI APPARAO (318126520L04), VEMPALA GOWRI SANKAR (317126520057), SHAIK FAHEEM (317126520049), SHEIK ABDUL MATEEN (317126520050), VOONNA HEMANTH (317126520060) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.D.S.S.RAVI KIRAN**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ACKNOWLEDGEMENT

We express our deep sense of gratitude to **Mr. D. S. SAI RAVI KIRAN**,Assistant Professor, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences for his valuable guidance and encouragement at every stage of work for the successful fulfillment of students.

We are very thankful to **Prof.T.V.HanumanthaRao**, Principal, and **Prof. B. Nagaraju,** Head of the Department, Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences for their valuable support and facilities provided to aid the students.

We express our sincere thanks to the non-teaching staff of Mechanical Engineering for their kind co-operation and support to carry on our project experimentation work.

We would also like to convey our deepest regards to all those who have contributed directly or indirectly for the completion of this project work.

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ABSTRACT:

This paper investigates the machinability characteristics of end milling operation to yield minimum tool wear with the maximum material removal rate using RSM based analysis. Twenty-seven experimental runs based on Box-Behnken Design of Response Surface Methodology (RSM) were performed by varying the parameters of spindle speed, feed and depth of cut in different weight percentage of reinforcements such as Silicon Carbide (SiC-5%, 10%,15%) and Alumina (Al_2O_3-5%) in aluminum 7075 metal matrix. RSM analysis was used to solve the multi-response optimization problem by changing the weightages for different responses as per the process requirements of quality or productivity. Optimal parameter settings obtained were verified through confirmatory experiments. Analysis of variance was performed to obtain the contribution of each parameter on the machinability characteristics. The result shows that spindle speed and weight percentage of Sic are the most significant factors which affect the machinability characteristics of hybrid composites. An appropriate selection of the input parameters

such as spindle speed of 1000 rpm, feed of 0.02 mm/rev, depth of cut of 1 mm and 5% of Sic produce best tool wear outcome and a spindle speed of 1838 rpm, feed of 0.04 mm/rev, depth of cut of 1.81 mm and 6.81 % of Sic for material removal rate.

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CHAPTER 1

INTRODUCTION

1.1.CNC MILLING:

CNC milling is a specific form of computer numerical control (CNC) machining. Milling itself is a machining process similar to both drilling and cutting and able to achieve many of the operations performed by cutting and drilling machines like drilling, milling uses a rotating cylindrical cutting tool .However, the cutter in a milling machine is able to move along multiple axes , and can create a variety of shapes and slots and holes. In addition, the work piece is often moved across the milling tool in different directions unlike the single axis motion of a drill.

CNC milling devices are the most widely used type of CNC machine. Typically, they are grouped by the number of axis on which they operate which are labelled with various letters. X and Y designate horizontal movement of the work piece (forward-and-back and side-to side on a flat plane). Z represents vertical up and down movement, while W represents diagonal movement across a vertical plane. Most machines offer from 3 to 5 axis, providing performance along at least the X,Y and Z axes. Advanced machines, such as 5-axis milling centers , require CAM programming for optimal performance due to the incredibly complex geometries involved in the machining process. These devices are extremely useful because they are able to produce shapes that would be nearly impossible using manual tooling methods.

Computer numerical control (CNC) is programmed code that represents instructions for precise movements to be carried out by machines. Indirectly, this code defines how to automatically create, produce, or transform a virtual object into a real one.

Based on this definition, a CNC machine must interact with a computer equipped with software that transforms numerical code into Cartesian coordinates. This allows the machine to work with a high degree of precision, just like a robot.

A CNC machine transforms raw material into a finished model through different methods, either by adding (additive) or removing (subtractive) material. The available techniques depend on the type of machine. A 3D printer or CNC milling machine are fine examples of additive and subtractive CNC machines, respectively.

1.1.1.CNC MILLING MACHINE:

Fig.1.1. CNC Milling Machine

There are several kinds of milling machines, which are designated by number of movement axes:

- **2-axis milling machines** can cut holes and slots in the x- and z-axes. In other words, this machine will only cut vertically and horizontally (but only in one direction).
- **3-axis milling machines** add the y-axis. This is the most common variety of milling machine. You can cut vertically and, in any direction, but an object like a sphere will need to be done one half at a time. This is because, even with three axes, it's not possible to cut from below.
- **4-axis milling machines** are more complex because they add the ability to rotate the x-axis, similar to a lathe.
- **5-axis milling machines** incorporate rotation in both the x- and y-axes. This is the most complete milling machine you can have. It allows you to shape bones, aerospace structures, car models, medical products, and pretty much anything else you can imagine.

1.2.Types of milling machines:

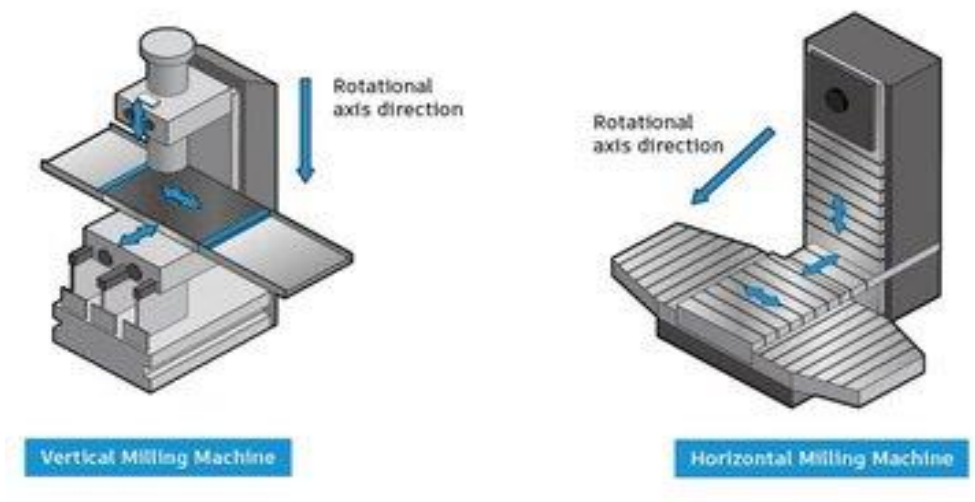


Fig.1.2. a) Vertical Milling Machine **b)**Horizontal Milling Machine

Now we know that a CNC milling machine is any milling machine controlled through a computer. Yet, apart from axis classifications, there are still several types of milling machines, whether manual or CNC:

- **Vertical mill:** This 3-axis milling machine consists of a table, which acts as a work surface, below an arm, to which the spindle is attached. Both the table and the arm are connected to a vertical column, and the spindle is vertically oriented. Generally speaking, the table moves up and down along the z-axis in order to meet the arm, which is fixed. However, how the table and the spindle move in relation to each other depends on the type of vertical mill. In a **turret vertical mill**, the spindle is stationary and the table moves along both the x- and y-axes. In a **bed vertical mill**, the table can only be moved along the x-axis, while the spindle can travel along the length of the arm in the y-axis direction.
- **Horizontal mill:** This milling machine is similar to a vertical mill, except that the spindle is oriented horizontally instead of vertically. While generally considered less versatile than vertical mills, horizontal mills are better-suited to longer or heavy pieces of work. **A universal horizontal mill** has the additional capacity to rotate the table around the z-axis (making it a 4-axis milling machine).
- **Knee mill:** Any kind of mill where the table moves up and down the column according to an adjustable knee.

1.2.1.Types of milling tools:

For each machine, you can find different sets of tools that perform different cuts. Some bigger, more industrial machines can even change the tool mid-job.

Fig. 1.3. Types of Tool Wear

Different tools are designed for different materials, and it's important to choose the perfect tool for the job. Failure to do so could result in unwanted damage to the material, the tool, or both.

Let's compare wood and steel: If you choose an overly strong steel tool to cut wood, you could end up losing the workpiece. Meanwhile, if you use wood tools for steel, you will certainly end up breaking the tool and the machine.

As stated earlier, the most basic tool is a milling cutter, which kind of resembles a drill bit, but with teeth designed to remove material in ways other than just drilling. Cutters can vary in shape and size as well as in teeth orientation and spacing.

1.2.2.IMPORTANCE OF CNC MILLING:

Digital technologies and CNC milling machines allow for the resolution of many problems which cannot be easily solved using prior methods. The technology approaches the working process in a way that's both more effective and more efficient.

For example, without a CNC milling machine, the process of cutting metal for car parts or even aerospace components would be much riskier. With the support of computer programs, one can access and create high definition designs that are easily converted into Cartesian coordinates. This process even helps lower the costs of prototyping!

But these technological machines aren't only for industrial use. Here are a few other areas to which CNC milling can be applied:

- cabinets

- furniture
- woodworking
- instruments
- aluminum machining
- prototyping and modeling
- sculpture
- signs

There are also a wide range of (hard and soft) solid materials that a CNC milling machine can cut:

- aluminum
- steel
- titanium
- copper
- bronze
- zinc
- PVC
- nylon
- wood
- plywood
- extruded polyurethane
- stone

1.3.TOOL WEAR:

Tool wear monitoring/sensing should be one of the primary objectives in order to produce the required end products in an automated industry so that a new tool may be introduced at the instant at which the existing tool has worn out, thus preventing any hazards occurring to the machine or deterioration of the surface finish. Cutting tools may fail due to the plastic deformation, mechanical breakage, cutting edge blunting, and tool brittle fracture or due to the rise in the interface temperatures.

Throughout the world today, there is a continuous struggle for cheaper production with better quality. This can be achieved only through optimal utilization of both material and human resources. Machining operations comprise a substantial portion of the world's manufacturing infrastructure. They create about 15% of the value of all mechanical components manufactured worldwide. Because of its great economic and technical importance, a large amount of research has been carried out in order to optimize cutting process in terms of improving quality, increasing productivity and lowering cost.

Tool wear influences cutting power, machining quality, tool life and machining cost. When tool wear reaches a certain value, increasing cutting force, vibration and cutting temperature cause surface integrity deteriorated and dimension error greater than tolerance. The life of the cutting tool comes to an end. Then the cutting tool must be replaced or ground and the cutting process is interrupted. The cost and time for tool replacement and adjusting machine tool increases cost and decreases the productivity. Hence tool wear relates to the economics of machining and prediction of tool wear is of great significance for the optimization of cutting process.

TOOL WEAR:

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact, between the chip and work piece, under conditions of very high stress at high temperature. The situation is further aggravated due to the

existence of extreme stress and temperature gradients near the surface of the tool. During cutting, cutting tools remove the material from the component to achieve the required shape, dimension and finish. However, wears are occurring during the cutting action, and it will result in the failure of the cutting tool. When the tool wear reach certain extent, the tool or edge change has to be replaced to guarantee the ordinary cutting action.

Tool wear is measured through METZER tool makers microscope (Model: Metz-1395) was used for measurement of tool flank surface wear on the carbide coated cutting tool insert after end milling operation.

1.3.1 TOOL WEAR METHODOLOGY:

Under high temperature, high pressure, high sliding velocity and mechanical or thermal shock in cutting area, cutting tool has normally complex wear appearance, which consists of some basic wear types such as crater wear, flank wear, thermal crack, brittle crack, fatigue crack, insert breakage, plastic deformation and build-up edge. The dominating basic wear types vary with the change of cutting conditions.

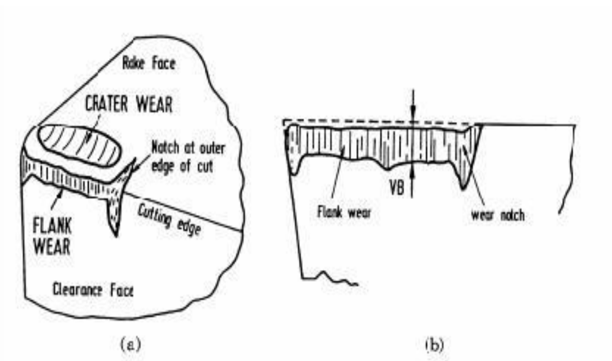


Fig.1.4. Types of Tool Wear

Crater wear: In continuous cutting, for example in turning operation, crater wear normally forms on rake face. It conforms to the shape of the chip underside and reaches the maximum depth at a distance away from the cutting edge where highest temperature occurs. At high cutting speed, crater wear is often the factor that determines the life of the cutting tool, because the tool edge is weakened by the severe cratering and eventually fractures. Crater wear is improved by selecting suitable cutting parameters and using coated tool or ultra-hard material tool.

Flank wear: Flank wear is caused by the friction between the newly machined work piece surface and the tool flank face. It is responsible for a poor surface finish, a decrease in the dimension accuracy of the tool and an increase in cutting force, temperature and vibration. Hence the width of the flank wear land “VB” is usually taken as a measure of the amount of wear and a threshold value of the width is defined as tool reshape criterion.

1.4 WEAR MECHANISM:

In order to find out suitable way to slow down the wear process, many research works are carried out to analyze the wear mechanism in metal cutting. It is found that tool wear is not formed by a unique tool wear mechanism but a combination of several tool wear mechanisms.

Tool wear mechanisms in metal cutting include abrasive wear, adhesive wear, delamination wear, solution wear, diffusion wear, oxidation wear, electrochemical wear, etc. Among them, abrasive wear, adhesive wear, diffusion wear and oxidation wear are very important.

Abrasive wear: Abrasive wear is mainly caused by the impurities within the work piece material, such as carbon, nitride and oxide compounds, as well as the built-up fragments. This is a mechanical wear, and it is the main cause of the tool wear at low cutting speed.

Adhesive wear: The simple mechanism of friction and wear proposed by Bowden and Tabor is based on the concept of the formation of welded junctions and subsequent destruction of these. Due to the high pressure and temperature, welding occurs between the fresh surface of the chip and rake face because of the chip flowing on the rake face results in chemically clean surface.

Severe wear is characterized by considerable welding and tearing of the softer rubbing surface at high wear rate, and the formation of relatively large wear particles. Adhesion wear occurs mainly at low machining temperatures on tool rake face, such built up edge (BUE).Under mild wear conditions, the surface finish of the sliding surfaces improves.

Oxidation wear: High temperatures and the presence of air mean oxidation for most metals. A slight oxidation of tool face is helpful to reduce the tool wear. It reduces adhesion, diffusion and current by isolating the tool and the work piece. But at high temperature soft oxide layers, for example WO3, TiO2, are formed rapidly, and then taken away by the chip and the work piece. This results in a rapid tool material loss, which is oxidation wear.

Chemical wear: Corrosive wear (due to chemical attack of a surface)

Fatigue wear: Fatigue wear is often a thermo-mechanical combination. Temperature fluctuations and the loading and unloading of cutting forces can lead to cutting edge cracking and breaking. Intermittent cutting action leads to continual generation of heat and cooling as well as shocks of cutting-edge engagement.

Under different cutting conditions dominating wear mechanisms are different. For a certain combination of cutting tool and work piece, the dominating wear mechanisms vary with cutting temperature. According to the temperature distribution on the tool face, it is assumed that crater wear is mainly caused by abrasive wear, diffusion wear and oxidation wear, but flank wear mainly dominated by abrasive wear due to hard second phase in the work piece material.

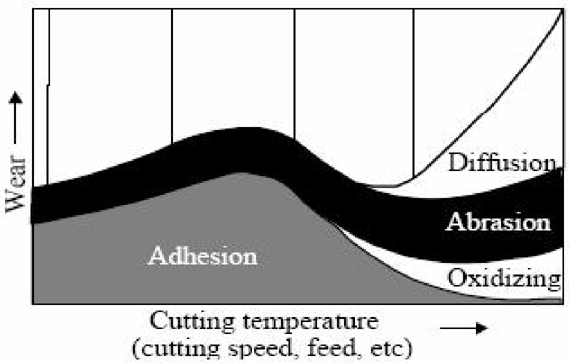


Fig.1.5. Wear mechanisms

1.4.1. PREDICTION OF TOOL WEAR:

Prediction of tool wear is complex because of the complexity of machining system. Tool wear in cutting process is produced by the contact and relative sliding between the cutting tool and the work piece and between the cutting tool and the chip under the extreme conditions of cutting area; temperature at the cutting edge can exceed 530°C and pressure is greater than 13.79 N/mm2. Any element changing contact conditions in cutting area affects tool wear**.** Figure 3.3 shows influencing elements of the tool wear. These elements come from the whole machining system comprising work piece, tool, interface and machine tool.

Work piece: It includes the work piece material and its physical properties (mechanical and thermal properties, microstructure, hardness, etc.), which determine cutting force and energy for the applied cutting conditions.

Tool: The tool material, tool coatings and tool geometric design (edge preparation, rake angle, etc.) need to be appropriately chosen for different operations (roughing, semi roughing, or finishing). The optimal performance of a cutting tool requires a right combination of the above tool parameters and cutting conditions (cutting speed, feed rate, depth of cut).

Fig.1.6. Influencing elements of tool wear

Interface: It involves the interface conditions. In 80% of the industrial cutting applications, coolants are used to decrease cutting temperatures and likely reduce tool wear. Increasingly new technologies, such as the minimum liquid lubrication, have been developed to reduce the cost of coolant that makes up to 16% of the total machining costs.

Dynamic characteristics: The dynamic characteristic of the machine tool, affected by the machine tool structure and all the components taking part in the cutting process, plays an important role for a successful cutting. Instable cutting processes with large vibrations (chatters) result in a fluctuating overload on the cutting tool and often lead to the premature failure of the cutting edge by tool chipping and excessive tool wear.

The problem of tool wear monitoring in machining operation has been active area of research. This is because tool change strategies, product quality, tooling costs, and productivity are all influenced by tool wear. Reduction in production cost and increase in productivity can be realized by making the most use of a tool's life and therefore increasing the time between tool change.

1.4.2. EFFECT OF TOOL WEAR ON TECHNOLOGICAL PERFORMANCE:

CONSEQUENCES OF TOOL WEAR:

•Decrease the dimension accuracy;

•Increase the surface roughness;

•Increase the cutting force;

•Increase the temperature;

•Likely cause vibration;

•Lower the production efficiency, component quality;

•Increase the cost.

1.5.Material removal rate (M.R.R):

Material removal rate: (MRR) is the amount of material removed per time unit (usually per minute) when performing machining operations such as using a lathe or milling machine. The more material removed per minute, the higher the material removal rate. The 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).

MRR = wDd/t where, w-width of specimen (100 mm); D-tool diameter (20 mm) & d-depth of cut (mm); t-time taken for material removal in minutes.

Introduction to statistical software:

1.6. MINITAB SOFTWARE:

Minitab is a software product that helps you to analyze the data. This is designed essentially for the Six Sigma professionals. It provides a simple, effective way to input the statistical data, manipulate that data, identify trends and patterns, and then extrapolate answers to the current issues. This is most widely used software for business of all sizes - small, medium and large. Minitab provides a quick, effective solution for the level of analysis required in most of the Six Sigma projects. Minitab Inc. is one of the dominant providers of the statistical software for quality improvement. Huge number of companies trust Minitab, thousands of colleges use Minitab software for teaching. Minitab Inc. is a company headquarter in State College, Pennsylvania, with subsidiaries in the United Kingdom, France, and Australia.

The different types of windows in Minitab are:

Session Window:

This window displays the statistical results of data analysis.

Worksheet Window:

This window contains rows and columns which are used to enter and manipulate the data. This window looks like a spread sheet but the changes cannot be saved automatically.

The Graph window:

This window will be opened when the graph is generated.

Report Window:

With this window you can sort out your results

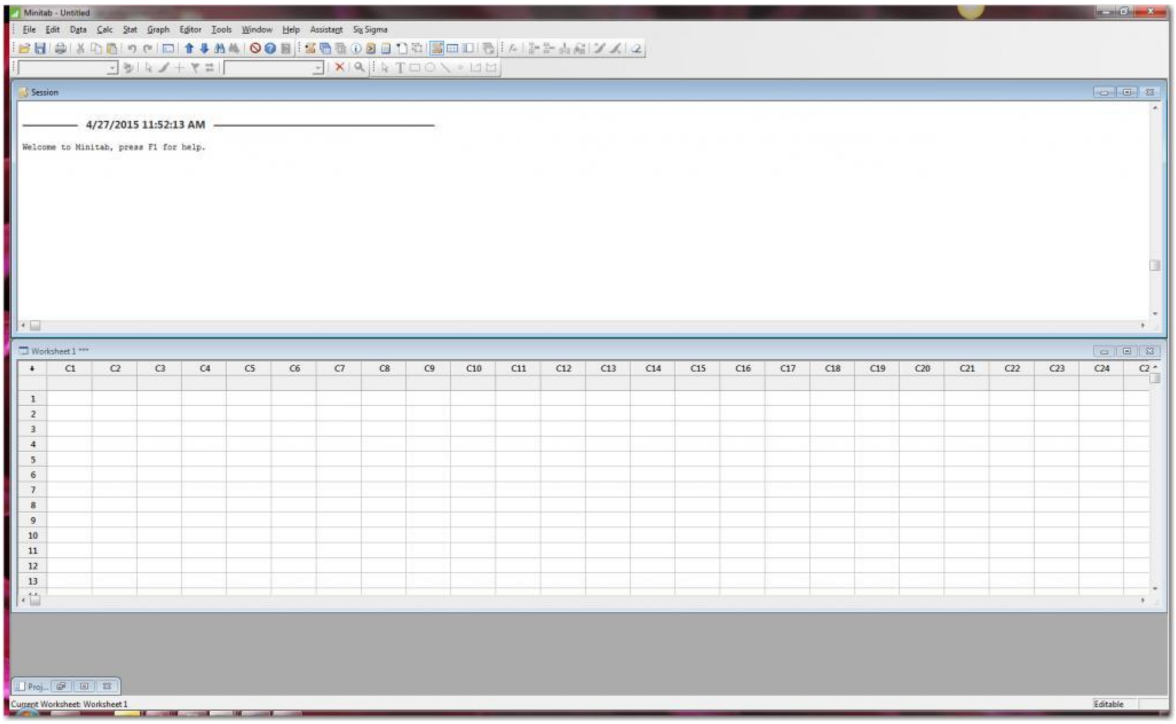


Fig.1.7. Layout of Minitab software

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was last published 1986, and there has been no significant development since then. Minitab is distributed by Minitab, Inc., a privately owned company headquartered in State College, Pennsylvania. Minitab introduces the most commonly used features such as you use functions, create graphs, and generate statistics. We use a sampling of Minitab’s features to see the range of features and statistics that Minitab provides. Most statistical analyses require a series of steps, often directed by background knowledge or by the subject area we are investigating.

There are three datatypes in Minitab:

- Numerical Data
- Text Data
- Date/Time

Numerical Data:

The Numerical data is aligned to the right side of the column. This is essentially used for statistical calculations

Text Data:

The text cannot be used for computations or calculations. If column 1 has text in it, the label of the column will be changed to CI-T.

Date/Time:

Minitab Recognizes 3/5/00 as date and 5:30 as a time but the date and time are internally stored as numbers. The column label can be identified as date and time by mentioning D after the column name. Minitab can change Data types.

Minitab can do the following transformations:

- Numeric to text
- Text to numeric
- Date/Time to text
- Date/Time to numeric
- Numeric to Date/Time
- Text to Date/Time

To make the changes in Minitab, you need to select MANIP > CHANGE DATA TYPE. Then, select the option that you want to change and fill in the dialog box then the changes can be seen.

How to save the data in Minitab:

In Minitab you can save data in two different formats. You can save the worksheet or you can save the whole project. Saving the Worksheet individually is more preferable rather than saving the whole project.

How to save the data in worksheet:

- Select File at the top select save current worksheet as.......
- Use the arrow beside the save in : field
- In the file name field, type the name of the worksheet. While saving Minitab will automatically add an extension as MTW for the worksheet
- Click Save

The following illustrate the analysis steps in typical Minitab software:

- Exploring data with graphs
- Conducting statistical analyses and procedures
- Assessing quality
- Designing an experiment
- Using shortcuts to automate future analyses
- Generating a report
- Preparing worksheets

- Customizing Minitab to fit your ne your needs
- Real-life data analysis situations
- Brief summaries of statistical capabilities
- Emphasis on important components of the output

CHAPTER 2

Literature Survey:

ASHOK KUMAR.U , LAXMINARAYANA.P (2013) [1] : The Present work deals with the effects of various milling parameters such as spindle speed, feed rate, and depth of cut on the surface roughness of finished components. The experiments were conducted on AISI 304 S.S plate material on vertical milling machine using carbide inserts and by using Taguchi's technique including L9 orthogonal array. The analysis of mean and variance technique is employed to study the significance of each machining parameter on the surface roughness.

SUNILKUMAR, S.PANSHETTY, PARAG V.BUTE (2016) [2]:The present work highlights the optimization of Computerized Numerical Control (CNC) milling Process Parameters to provide a better surface finish and high Material Removal Rate (MRR). As Taguchi's method reduces the number of experiments, it is used for optimization of machining parameters. It is applied to find out the influence of various machining parameters like Speed, Feed rate, Depth of cut on Surface finish and MRR. The material used in this experiment is Al 7075 of size 100mm*100mm*10mm and the pocketing operation of size 20mm*20mm is carried out on vertical CNC milling machine by 12 mm carbide tool. L9 Orthogonal Array (OA) is used to carry out the experimentation. MINITAB-14 Software is used to analyze the result. Surface roughness (Ra) was measured and the MRR values were calculated to determine optimum levels. Results obtained were plotted for Ra, MRR v/s Speed, feed rate, depth of cut. In this Study, it is observed that the order of Significance of the main Variable for Surface Roughness (Ra) is Speed; Feed

&Depth of Cut (DOC) whereas for MRR, the Order of Significance is DOC, Feed rate & Speed.

N.GOSH, Y.B RAVI ,A.PATRA, S.MUKHOPADYAY (2007) [3]: In this work, a neural network-based sensor fusion model has been developed for tool condition monitoring (TCM). Features extracted from a number of machining zone signals, namely cutting forces, spindle vibration, spindle current, and sound pressure level have been fused to estimate the average flank wear of the main cutting edge. Novel strategies such as, signal level segmentation for temporal registration, feature space filtering, outlier removal, and estimation space filtering have been proposed. The proposed approach has been validated by both laboratory and industrial implementations.

MALAY, KISHAN GUPTHA, JAIDEEP GANGWAR (2016) [4]: CNC Vertical Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. During the face milling process, the material is removed by the 10 mm Día tool. The effects of various parameters of milling process like spindle speed, depth of cut, feed rate have been investigated to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by a Standard Orthogonal Array. The results of analysis of variance (ANOVA) indicate that the feed Rate is most influencing factor for modeling surface finish. The graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish. The optimal set of process parameters has also been predicted to maximize the surface finish

GIANNI CAMPATELLI, LORENZO LORENZINI, ANTONIO SCIPPA (2014) [5]: Due to the urgent need for global reductions of environmental impacts, many studies have been carried out in different fields. One of the most important sectors is manufacturing, particularly due to the high-power consumption of the production machines of manufacturing plants. This paper focuses on the efficiency of the machining centres and provides an experimental approach to evaluate and optimize the process parameters in order to minimize the power consumption in a milling process performed on a modern CNC machine. The parameters evaluated are the cutting speed, the axial and radial depth of cut, and the feed rate. A lubrication strategy has been chosen based on previous studies: all the tests have been carried out using dry lubrication in order to eliminate the environmental impact due to lubricant without substantially affecting the energy consumption. The process has been analysed using a Response Surface Method in order to obtain a model fit for the fine tuning of the process parameters.

S. MOSHAT, S. DATTA, A. BANDYOPADYAY, P.PAL (2010) [6]: In order to build up a bridge between quality and productivity, the present study highlights optimization of CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR). The surface finish and material removal rate have been identified as quality attributes and are assumed to be directly related to productivity. An attempt has been made to optimize aforesaid quality attributes in a manner that these multi-criterions could be fulfilled simultaneously up to the expected level. This invites a multi-objective optimization problem which has been solved by PCA based Taguchi method. To meet the basic assumption of Taguchi method; in the present work, individual response correlations have been eliminated first by means of Principal Component Analysis (PCA). Correlated responses have been transformed into uncorrelated or independent quality indices called principal components. The principal component, imposing highest accountability proportion, has been treated as single objective function for optimization (multi-response performance index). Finally, Taguchi method has been adapted to solve this optimization problem.

BHARGAV PATEL et al (2014) [7] : CNC milling is an area of interest for engineers around the world to increase the productivity, flexibility and for machining the complex shapes. Temperature measurement during end milling process is carried out using Cr-Al thermocouple to study the effect of various process parameters on temperature during machining. Conclusions made from contour plots and response surface diagrams are critically discussed.

ANTONIO FAVERO FILHO, LEONARDO ROSA RIBEIRO DA SILVA (2014) [8] : The nickel-based alloys have a growing demand in many fields due to their outstanding properties at high temperatures. These properties lead to relatively low machinability, one of the main obstacles to its more extensive use. Improvements in cutting tool quality are one of the key points to overcome the challenges. The decrease to a submicron scale of the grains of cemented carbide tools is one of the alternatives to improve the machinability of the nickel-based superalloys. Simulations using the finite element method of the effective plastic strain, validated by the measurement of experimental machining power, showed that the up milling presented around 14% more plastic deformation than the down milling, which combined with the work-hardenability of the Inconel 718 explains the shorter tool life of this condition.

Y.S. Liao et al [9] : conducted End milling of Inconel 718 under various cutting speeds by cemented carbide tools, and found that the increase of cutting temperature and strain hardening are responsible for the difficulty at low speed cutting. Design of experiments (DOE), is one of the most important statistical tools of TQM for designing high quality systems at reduced Cost as a milling technique, this means that a design can be specified on a computer using cad tools, and that a computer can handle the milling process. During CNC milling the computer translates the design into instructions on how the tool needs to move to create the shape. Typically, the tool can move up down, or tilt at an angle, and the table moves the part laterally

PITTA AND MOTTO et al [10] : have predicted the temperature of Ti-6Al-4V work piece in Face Milling. They used infrared camera to measure the work piece temperature and then a rheological model was developed and calibrated using different milling tests. The number of center points at the origin and the distance “a” of the axial runs from the design center are two parameters in the CCD design. The center runs contain information about the curvature of the surface, if the curvature is significant, the additional axial points allow for the experimenter to obtain an efficient estimation of the quadratic terms

Richardson, Keavy and Dailami et al [11] : Had developed a model of cutting induced work piece temperatures during dry milling. A large number of experimental works have to be carried out when the number of the process parameters increases. Therefore, to reduce the number of experiments and to obtain good quality of investigation the term named Design of experiments (DOE) is getting familiar in all over the world.

P.OK0KPUJIE et al[12] [2019] : It study various application of this CNC machining techniques such as minimum quantity lubricant, cryogenic cooling, flood cooling, dry, high pressure coolant, compressed air / vapor /gas as coolant, solid lubricant/cooling and vegetable oil and their effect during machining for sustainable development If this depth of cut is not properly studied, it will course vibration that will lead to failure of the cutting tool; this result is in line with observations made by [40] in their study of tool wear prediction

Mohd Shahir Kasim, C. H. Che Haron [13] [2014] : This paper presents the effect of cutting parameters on the cutting force when machining Inconel 718. Response surface methodology (RSM) was used in the experiment, and a Box–Behnken design was employed to identify the cause and effect of the relationship between the four cutting parameters (cutting speed, feed rate, depth of cut and width of cut) and cutting force. The ball-nose type of end mill with donwmill approach was maitainedthrougout the experiment. The forces were measured using Kistler dynamometer during straight line machining strategy. The result shows that the radial depth of cut was the dominating factor controlling cutting force, it was followed by axial depth of cut and feed rate. The prediction cutting force model was developed with the average error between the predicted and actual cutting force was less than 3%.

OKOKPUJIE et al [14] : carried out dry machining of Al6061 in an end milling operation, with four independent variables such as cutting speed, axial depth of cut, feed rate and radial depth of cut was investigated; After machining, the surface roughness was measure and analyzed with ANOVA. The result shows that feed rate and cutting speed had great influence on the surface roughness. carried out experimental analysis on HSS cut tool on dry machining of aluminum alloy and discovered that the depth of cut is very influential. If this depth of cut is not properly studied, it will course vibration that will lead to failure of the cutting tool; this result is in line with observations made by [40] in their study of tool wear prediction.

M. Seeman,G.Ganesan,R.Karthikeyan,A.Velayudham[15][2010]: Metal matrix composites (MMC) have become a leading material among composite materials, and in particular, particle reinforced aluminum MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials because of the hardness and abrasive nature of reinforcement element-like silicon carbide particles (Sic). In this study, an attempt has been made to model the machinability evaluation through the response surface methodology in machining of homogenized 20% Sic LM25 Al MMC manufactured through stir cast route. The combined effects of four machining parameters including cutting speed (*s*), feed rate (*f*), depth of cut (*d*), and machining time (*t*) on the basis of two performance characteristics of flank wear (VB_{max}) and surface roughness (Ra) were investigated. The contour plots were generated to study the effect of process parameters as well as their interactions. The process parameters are optimized using desirability-based approach response surface methodology.

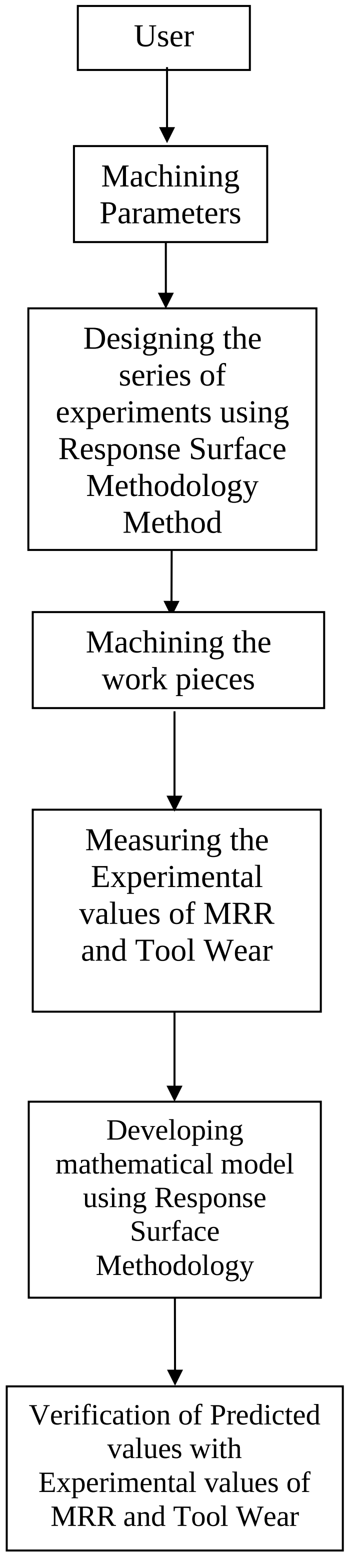
Rashid Ali Laghari, Jianguang Li, ZhengyouXie& Shu-qi Wang [16] [2018]: Nowadays metal matrix composites are widely utilized in major industries such as aerospace and automotive because of their excellent properties in association with non-reinforced. This research work is attempted to analyse the consequence of cutting parameters on tool life and surface quality. The experimental work is consisting of turning Al/Sic (45%SiCp) weight with uncoated Carbide tools and the effect of three machining parameters including depth of cut, feed, and speed. Tool life and surface roughness have considered as process response for investigation. The predictive model has been developing to optimize the machining parameters in accordance to Box–Behnken design in Minitab 17, the contour plots the surface plot and response optimizer have made to study the influence of machining parameters and their interactions. ANOVA was carried out to identify the key factor affecting the tool life and surface roughness. The maximum tool life is 10.511 (min) and least surface roughness was observed 0.044 µm. The abrasion and adhesive have the principle wear mechanism observed in machining process. Response surface methodology (RSM) approach have used to optimize the machining parameters, and the RSM model found more than 95% confidence level.

U. Natarajan, PR. Periyanan& S. H. Yang [17] [2011]: In the present trend, new fabrication methods for producing miniaturized components are gaining popularity due to the recent advancements in micro-electro mechanical systems. Micro-machining differs from the traditional machining with the small size tool, resolution of *x*–*y* and *z* stages. This paper focuses RSM for the multiple response optimization in micro-end milling operation to achieve maximum metal removal rate (MRR) and minimum surface roughness. In this work, second-order quadratic models were developed for MRR and surface roughness, considering the spindle speed, feed rate and depth of cut as the cutting parameters, using central composite design. The developed models were used for multiple-response optimization by desirability function approach to determine the optimum machining parameters. These optimized machining parameters are validated experimentally, and it is observed that the response values are in good agreement with the predicted values.

CHAPTER 3

3.1.EXPERIMENTAL METHODOLOGY:

3.1.1METHODOLOGY:



3.2.SELECTION OF MATERIAL:

Aluminum alloy are strong yet light metals that have found uses in almost every market. An alloy is a mixture of metals that, when together, are more useful than their constituents alone. A base metal (in this case aluminum), can be thought to be “improved” by small quantities of different metals, known as alloying elements. Alloys have been invented to provide stronger, more conductive, and/or more resilient materials for designing new ideas, and have revolutionized our engineering capabilities. Aluminum is a very common metal that has many useful alloys; so many in fact that the Aluminum Association has defined classes of these alloys using a numbered-naming scheme based on alloying elements.

Physical Properties of 7075 Aluminium:

7075 aluminium is composed of 90.0% Al, 5.6% Zn, 2.5%Mg, 0.23%Cr, and 1.6% Cu, though these numbers nominally fluctuate depending upon manufacturing factors. Its density is 2.81 g/cm3 (0.102 lb/in^3), which is relatively light for a metal. 7075 aluminium alloy is one of the strongest aluminium alloys available, making it valuable in high-stress situations. The copper content of 7075 aluminium increases its susceptibility to corrosion, but this sacrifice is necessary to make such a strong-yet-workable material.

7075 aluminium alloy can be further improved by how it is strengthened using a process known as heat-treatment, sometimes referred to as “tempering.” This method uses high heat (300-500 ºC) to reconfigure the metal’s crystal structure to strengthen its overall mechanical properties, and can literally make-or-break a material.

Tbale.3.0. Mechanical Properties:

Mechanical Properties	Metric
Ultimate Tensile Strength	572 MPa
Tensile Yield Strength	503 MPa
Shear Strength	331 MPa
Fatigue Strength	159 MPa
Modulus of Elasticity	71.7 GPa
Shear Modulus	26.9 GPa

Applications of 7075 Aluminum:

Type 7075 aluminium is one the strongest aluminium alloys. Its high yield strength (>500 MPa) and its low density make the material a fit for applications such as aircraft parts or parts subject to heavy wear. While it is less corrosion resistant than other alloys (such as 5052 aluminium alloy, which is exceptionally resistant to corrosion), its strength more than justifies the downsides. Some major applications of 7075 aluminium alloy include:

- Aircraft fittings
- Gears and shafts
- Missile parts
- Regulating valve parts
- Worm gears
- Aerospace/defense applications

3.2.1Specifications of material used:

Material = Al 7075 alloy with constant percentage weights of Al2O3 (5%) & variable percentage weights of Sic (5%); Sic (10%) and Sic (15%)

1. Al7075 and 5% Al2O3 + 5% Sic

2. Al7075 and 5% Al2O3 + 10% Sic

3. Al7075 and 5% Al2O3 + 15% Sic

Dimensions of workpiece:

Work Piece Size: 130 mm X 100 mm X 50 mm (3 plates)

Table.3.1. Chemical composition of al7075 alloy:

Element	Percentage (%)
Cu	1.2 - 2
Cr	0.18 – 0.28
Mn	0.3
Mg	2.1 – 2.9
Si	0.4
Ti	0.2
Zn	5.1 – 6.1
Fe	0.5
Al	balance

3.3.EQUIPMENTS USED:

CNC MILLING MACHINE:

CNC milling, or computer numerical control milling, is a machining process which employs computerized controls and rotating multi-point cutting tools to progressively remove material from the workpiece and produce a custom-designed part or product. This process is suitable for machining a wide range of materials, such as metal, plastic, glass, and wood, and producing a variety of custom-designed parts and products.

Fig.3.1. End milling operations were carried out in a BHARAT FRITZ WERNER BF-1 universal milling machine with 2.2 kW motor capacity.

3.3.1.Tool used:

Cutting Tool: Carbide coated cutting tool inserts (AXMT 0903 PER-EML TT8020, Make: Taegu Tec)

The tool insert was mounted on a tool holder of designation TE90AX 220-09-L. Length and diameter of tool holder are 170 mm and 20 mm respectively. The end milling operation was done along the direction of width (100 mm) of the specimen.

Fig.3.2. Cutting Tools

Tool maker's microscope:

Holm arc's Tool maker's microscopes are multi-functional measuring instruments which are primarily used for inspection and measurement of miniature mechanical and electronic parts and tools. These microscopes are used to view and measure linear distances, thread pitch, thread angles, tool edges, tool wear surfaces etc.

Fig.3.3. Tool Maker's Microscope

Tool wear is measured through METZER tool makers microscope (Model: Metz-1395) was used for measurement of tool flank surface wear on the carbide coated cutting tool insert after end milling operation.

3.3.2.PROCESS VARIABLES USED IN EXPERIMENTATION:

The input welding parameters selected were:

- Spindle speed (Rpm)
- Feed rate (mm/min)
- Depth of cut (mm)
- Percentage weight of silicon carbide

Table.3.2. Process variables used in experiment:

S. No.	Parameters	Level I	Level II	Level III
1	**Spindle speed(N)** **Rpm**	1000	1500	2000
2	**Feed rate(f)** **mm/min**	0.02	0.03	0.04
3	**Depth of cut(d)** **mm**	1	1.5	2
4	**Percentage weight of silicon carbide** **%**	5	10	15

OUTPUT RESPONSES OBTAINED

1. Material Removal Rate (M.R.R):

After every experimentation material removal rate is calculated by the formula given below:

$$MRR = wDd/t$$

where,

w-width of specimen (100 mm);

D-tool diameter (20 mm) & d-depth of cut (mm);

t-time taken for material removal in minutes

After obtaining the material removal rate it is noted down in the table.

2. Tool Wear (VB):

Tool wear is measured through METZER tool makers microscope (Model: Metz-1395) was used for measurement of tool flank surface wear on the carbide coated cutting tool insert after end milling operation.

Design of experiments and optimisation:

3.4.Introduction to Design of Experiments:

“Design of Experiments” is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters and output responses. DOE has a wide range of applications, especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modeling and is a designed experimental approach which is far superior to unplanned approach, whereby, a systematic way will be used to plan the experiment, collect the data and analyze the data. A mathematical model has been developed by using analysis techniques such as ANOVA and regression analysis whereby the mathematical model shows the relationship between the input parameters and the output responses. Among the most prominently used DOE techniques are Response Surface Methodology with Central Composite Design, Taguchi's method and Factorial Design. In DOE, synergy between mathematical and statistical techniques such as Regression, Analysis of Variance (ANOVA), Non-Linear Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost-effective process. ANOVA helps to identify each factor effect versus the objective function.

Experimental design was first introduced in the 1920s by R. A. Fischer working at the agricultural field station at Roth Amsted in England. Fischer was concerned with arranging trials of fertilizers on plants to protect them against the underlying effect of moisture, gradient, nature of soils, etc. Fischer developed the basic principles of factorial design and the associated data analysis known as ANOVA during research in improving the yield of agricultural crops.

3.4.1.Advantages & Disadvantages of DOE:

DOE became a more widely used modeling technique superseding its predecessor one-factor-at- time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Apart from that, the mathematical model generated can be used as a prediction model which can predict the possible output responses based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE functions in such a manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Usually, experiments will have errors occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction of linear behavior. However, when it comes to nonlinear behavior, DOE does not always give the best results.

3.4.2. Response Surface Methodology (RSM):

The response surface methodology (RSM) is a widely used mathematical and statistical method for modeling and analyzing a process in which the response of interest is affected by various variables and the objective of this method is to optimize the response. The parameters that affect the process are called dependent variables, while the responses are called dependent variables.

It can be expressed as the dependent variable y is a function of X1 and X2.

$$Y=f(X1)+f(X2)+e$$

where Y is the response (dependent variable), X1 and X2 are independent variables and e is the experimental error.

Response surface is a method based on surface placement. Therefore, the main goals of an RSM study are to understand the topography of the response surface including the local maximum, local, minimum and ridge lines and find the region where the most appropriate response occurs.

The RSM investigates an appropriate approximation relationship between input and output variables and identify the optimal operating conditions for a system under study or a region of the factor field that satisfies the operating requirements. Box-Behnken designs (BBD) and central composite design (CCD) are two main experimental designs used in response surface methodology. Central composite rotatable design (CCRD) and face central composite design (FCCD) has also been applied to optimization studies in recent years.

The design of experiments (DOE) is the most important aspect of RSM. The DOE aims the selection of most suitable points where the response should be well examined. The mathematical model of the process is mostly related to design of experiments. Thus, the selection of experiment design has a great effect in determining the correctness of the response surface construction. The advantages offered by the RSM can be summarized as determining the interaction between the independent variables, modeling the system mathematically, and saving time and cost by reducing the number of trials. However, the most important disadvantage of the response surface method is that the experimental data are fitted to a polynomial model at the second level. It is not correct to say that all systems with curvature are compatible with a second-order polynomial model. In addition, experimental verification of the estimated values in the model should be done absolutely.

In early stage of D0E, screening experiments are performed. If there are many variables have little or more effect on the response, the variables which have large effects on response are identified. Therefore, the aim is to determine the design variables that have large effects for further investigation.

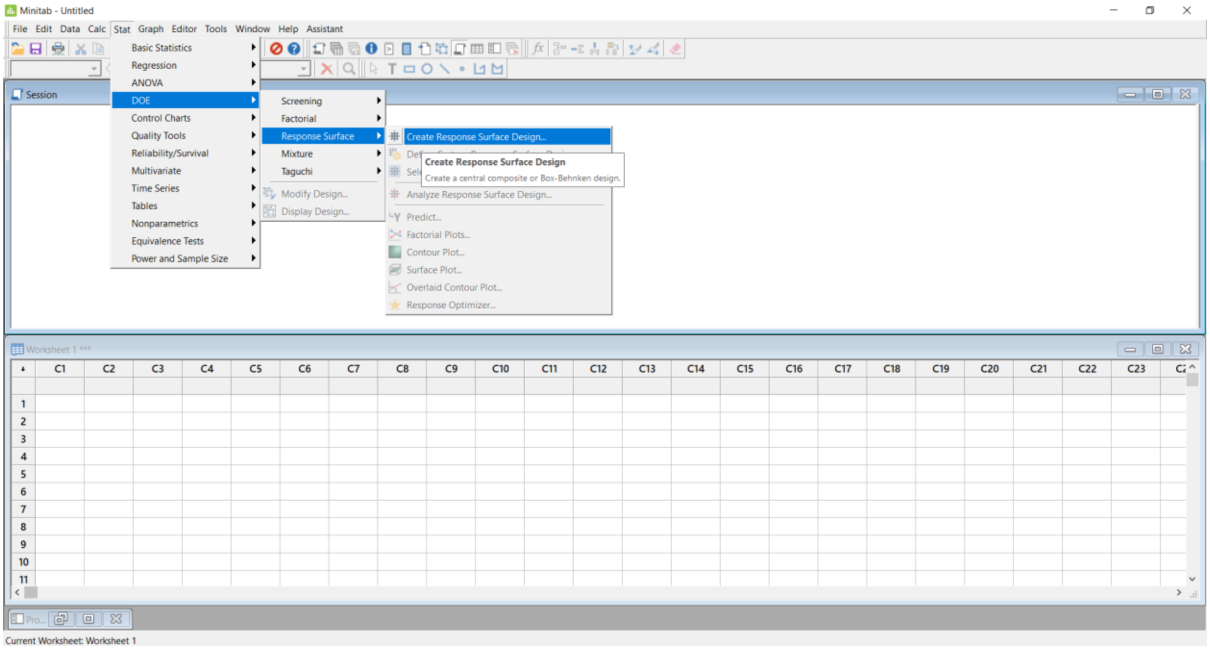
Box-Behnken design:

Box-Behnken designs are used to generate higher order response surfaces using fewer required runs than a normal factorial technique. The Box–Behnken designs of experiments provide modeling of the response surface. These designs are not based on full or fractional factorial designs. The design points are positioned at the middle of the subareas of the dimension k-1.

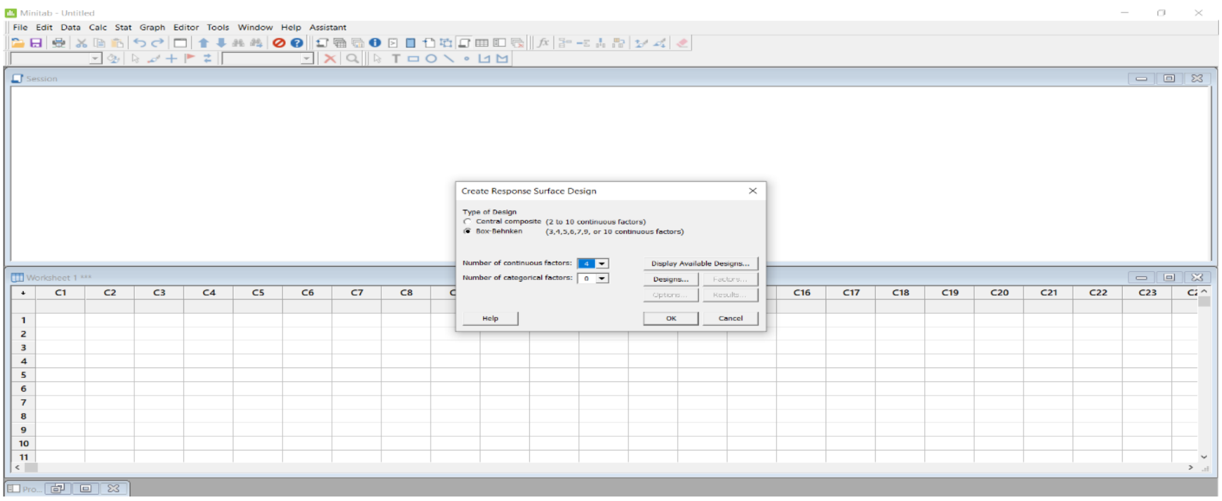
Using Minitab to Run a Response Surface design of experiment:

Initiate the experiment design

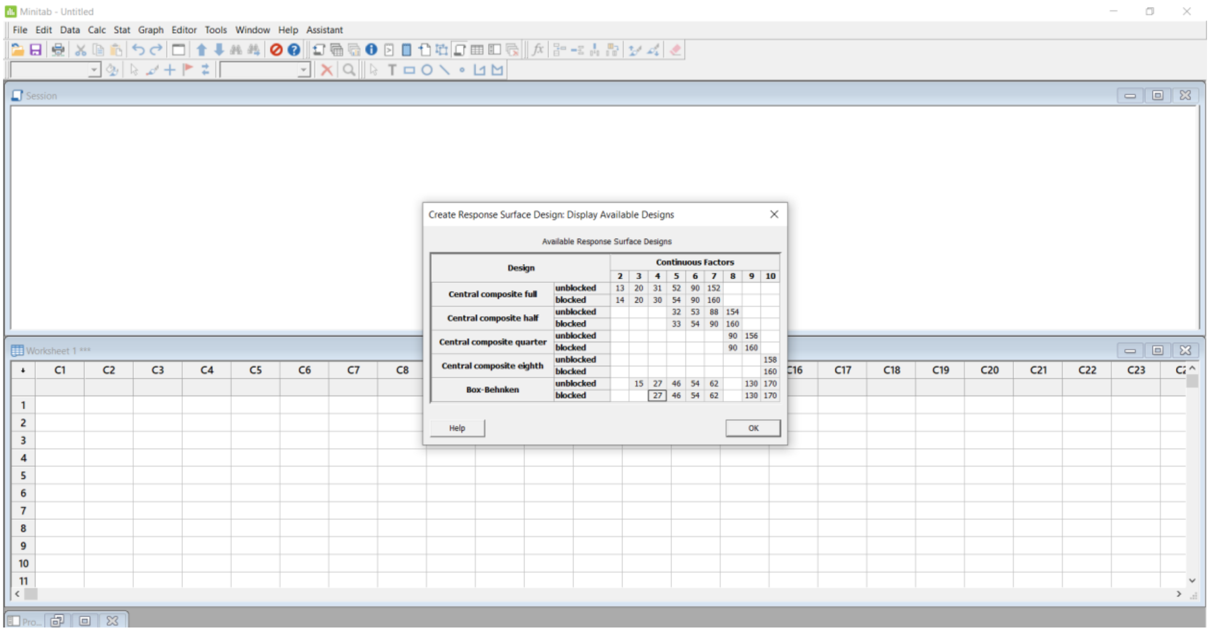
1. Click Stat → DOE → Response Surface → Create Surface Response Design.



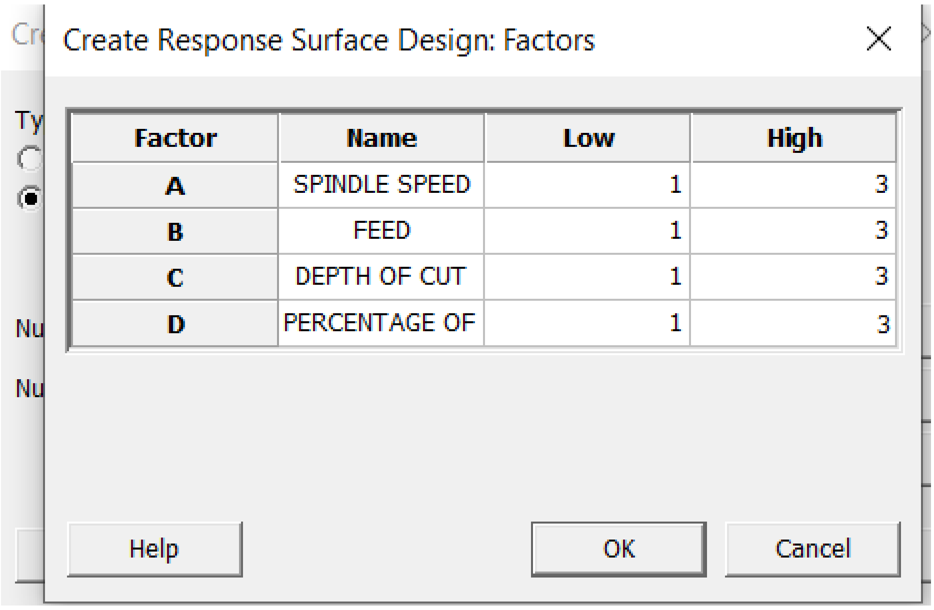
2. A new window named “Response surface design” pops up.



3. Then select “Box-Behnken” and select the number of continuous factors as “4”.



4. Then select “27” under Box – Behnken as shown above.

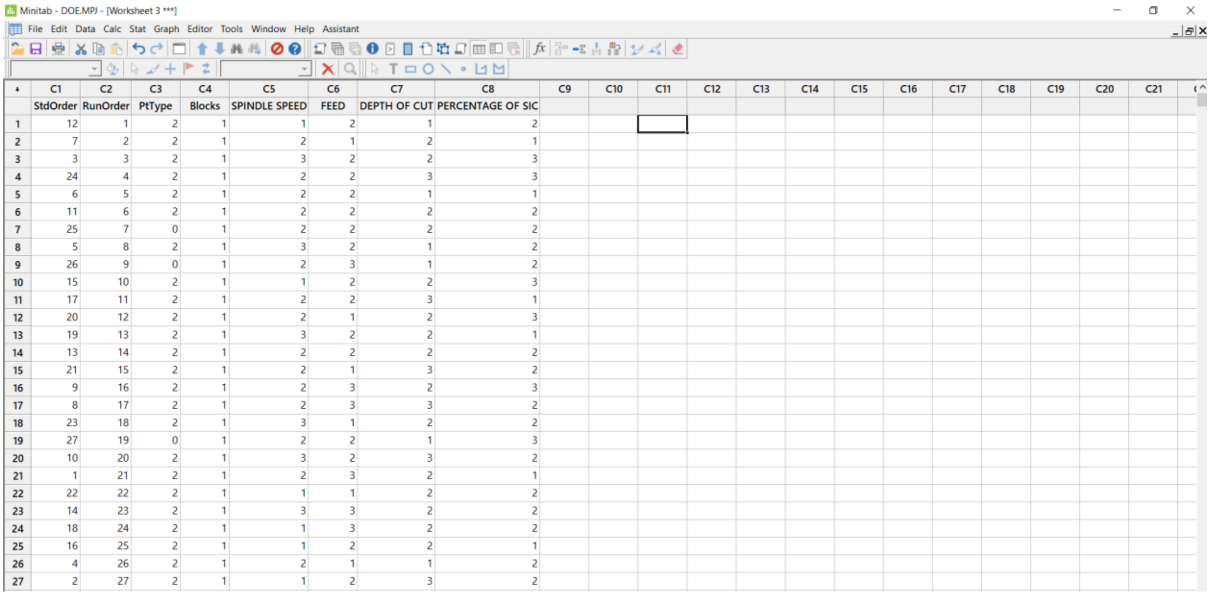


5. Then name the factors and give the numbering as shown above.

6. Then click on options and click “OK”

7. Then click on results and click “OK”

8. Then the design of experiment is shown on the worksheet as shown below.



Minitab - DOE.MPJ - [Worksheet 3 ***]

	C1 StdOrder	C2 RunOrder	C3 PtType	C4 Blocks	C5 SPINDLE SPEED	C6 FEED	C7 DEPTH OF CUT	C8 PERCENTAGE OF SIC
1	12	1	2	1	1	2	1	2
2	7	2	2	1	2	1	2	1
3	3	3	2	1	3	2	2	3
4	24	4	2	1	2	2	3	3
5	6	5	2	1	2	2	1	1
6	11	6	2	1	2	2	2	2
7	25	7	0	1	2	2	2	2
8	5	8	2	1	3	2	1	2
9	26	9	0	1	2	3	1	2
10	15	10	2	1	1	2	2	3
11	17	11	2	1	2	2	3	1
12	20	12	2	1	2	1	2	3
13	19	13	2	1	3	2	2	1
14	13	14	2	1	2	2	2	2
15	21	15	2	1	2	1	3	2
16	9	16	2	1	2	3	2	3
17	8	17	2	1	2	3	3	2
18	23	18	2	1	3	1	2	2
19	27	19	0	1	2	2	1	3
20	10	20	2	1	3	2	3	2
21	1	21	2	1	2	3	2	1
22	22	22	2	1	1	1	2	2
23	14	23	2	1	3	3	2	2
24	18	24	2	1	1	3	2	2
25	16	25	2	1	1	2	2	1
26	4	26	2	1	2	1	1	2
27	2	27	2	1	1	2	3	2

9. Copy the DOE to excel sheet and note down the corresponding factors.

10. After experimentation note down the values of Mrr and Tool wear in the excel sheet.

11. Then import the excel sheet to Minitab for further analysis.

Table.3.3. The final DOE is shown below:

S NO	**Spindle Speed, N (rpm)**	**Feed rate, f (mm/min)**	**Depth of cut, d (mm)**	**% Weight of Sic**	**Material removal rate, MRR (mm3/min)**	**Tool wear, VB (mm)**
1	1000	0.03	1	10	759.49	0.135
2	1500	0.02	1.5	5	805.97	0.188
3	2000	0.03	1.5	15	1258.8	0.401
4	1500	0.03	2	15	812.61	0.395
5	1500	0.03	1	5	756.3	0.184
6	1500	0.03	1.5	10	2148.9	0.249

7	1500	0.03	1.5	10	2148.9	0.249
8	2000	0.03	1	10	956.3	0.347
9	1500	0.04	1	10	1406.3	0.266
10	1000	0.03	1.5	15	834.45	0.231
11	1500	0.03	2	5	1506.3	0.25
12	1500	0.02	1.5	15	805.97	0.249
13	2000	0.03	1.5	5	2111.1	0.288
14	1500	0.03	1.5	10	2148.9	0.249
15	1500	0.02	2	10	1043.5	0.247
16	1500	0.04	1.5	15	1126	0.351
17	1500	0.04	2	10	2201.7	0.298
18	2000	0.02	1.5	10	1303.6	0.316
19	1500	0.03	1	15	762.71	0.289
20	2000	0.03	2	10	1463.4	0.379
21	1500	0.04	1.5	5	2109.4	0.233
22	1000	0.02	1.5	10	698.82	0.136
23	2000	0.04	1.5	10	2160	0.359
24	1000	0.04	1.5	10	925.98	0.199
25	1000	0.03	1.5	5	1088.7	0.116
26	1500	0.02	1	10	734.13	0.202
27	1000	0.03	2	10	812.61	0.188

13. Analyze the model results.

CHAPTER 4

RESULTS AND DISCUSSION:

4.1. ANALYSIS OF VARIANCE:

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

Characteristics of ANOVA:

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So, ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

4.2. MATHEMATICAL MODELING:

Linear Regression equation:

$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots\ldots + \beta_k X_k$

Multiple linear regression equation:

Multiple linear regression equation is a second order polynomial equation of the form –

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{i^2} + \sum \sum_{i<j} \beta_{ij} x_i x_j + \in$$

Where,

Y is the corresponding response

(1,2, . . ., S) are coded levels of S quantitative process variables

The terms are the second order regression coefficients

Second term is attributable to linear effect

Third term corresponds to the higher-order effects

Fourth term includes the interactive effects

The last term indicates the experimental error

4.3. TERMS & GRAPHS USED:

Regression table:

1. P-values

P-values (P) are used to determine which of the effects in the model are statistically significant.

If the p-value is less than or equal to α (0.05), conclude that the effect is significant.

If the p-value is greater than α, conclude that the effect is not significant.

2. Coefficients

Coefficients are used to construct an equation representing the relationship between the response and the factors.

3. R-squared

R and adjusted R represent the proportion of variation in the response that is explained by the model.

- R (R-Sq.) describes the amount of variation in the observed responses that is explained by the model.
- Predicted R reflects how well the model will predict future data.
- Adjusted R is a modified R that has been adjusted for the number of terms in the model. If we include unnecessary terms, R can be artificially high. Unlike R , adjusted R may get smaller when we add terms to the model.

4. Analysis of variance table:

P-values (P) are used in analysis of variance table to determine which of the effects in the model are statistically significant. The interaction effects in the model are observed first because a significant interaction will influence the main effects.

5. Estimated coefficients using uncoded units:

Minitab displays the coefficients in uncoded units in addition to coded units if the two units differ.

For each term in the model, there is a coefficient. These coefficients are useful to construct an equation representing the relationship between the response and the factors

Graphs:

1. Histogram of residuals:
Histogram of the residuals shows the distribution of the residuals for all observations

2. Normal plot of residuals
Graph is plotted between the residuals versus their expected values when the distribution is normal. The residuals from the analysis should be normally distributed. In practice, for balanced or nearly balanced designs or for data with a large number of observations, moderate departures from normality do not seriously affect the results. The normal probability plot of the residuals should roughly follow a straight line.

3. Residuals versus fits:
Graph is plotted between the residuals versus the fitted values. The residuals should be scattered randomly about zero.

4. Residuals versus order:
This graph plots the residuals in the order of the corresponding observations. The plot is useful when the order of the observations may influence the results, which can occur when data are collected in a time sequence or in some other

sequence. This plot can be particularly helpful in a designed experiment in which the runs are not randomized.

Table.4.1. Analysis of variance of material removal rate:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	8623869	615991	7.2	0.001
Linear	4	5033504	1258376	14.71	0
Spindle Speed, N (rpm)	1	1423577	1423577	16.64	0.002
Feed rate, f (mm/min)	1	2189990	2189990	25.6	0
Depth of cut, d (mm)	1	777187	777187	9.09	0.011
% Weight of Sic	1	642751	642751	7.51	0.018
Square	4	2697212	674303	7.88	0.002
Spindle Speed, N (rpm)*Spindle Speed, N (rpm)	1	1267541	1267541	14.82	0.002
Feed rate, f (mm/min) *Feed rate, f (mm/min)	1	465292	465292	5.44	0.038
Depth of cut, d (mm)*Depth of cut, d (mm)	1	1664303	1664303	19.46	0.001
% Weight of Sic*% Weight of Sic	1	1537254	1537254	17.97	0.001
2-Way Interaction	6	893152	148859	1.74	0.195
Spindle Speed, N (rpm)*Feed rate, f (mm/min)	1	98986	98986	1.16	0.303

Spindle Speed, N (rpm)*Depth of cut, d (mm)	1	51524	51524	0.6	0.453
Spindle Speed, N (rpm)*% Weight of Sic	1	89416	89416	1.05	0.327
Feed rate, f (mm/min) *Depth of cut, d (mm)	1	288922	288922	3.38	0.091
Feed rate, f (mm/min) *% Weight of Sic	1	241769	241769	2.83	0.119
Depth of cut, d (mm)*% Weight of Sic	1	122535	122535	1.43	0.254
Error	12	1026519	85543		
Lack-of-Fit	10	1026519	102652	*	*
Pure Error	2	0	0		
Total	26	9650388			

Regression equation for material removal rate in uncoded units:

Material removal rate, MRR (mm3	=	-13254 + 5.51 Spindle Speed, N (rpm) + 141290 Feed rate, f (mm/min) + 5619 Depth of cut, d (mm) + 725 % Weight of Sic - 0.001950 Spindle Speed, N (rpm)*Spindle Speed, N (rpm) - 2953679 Feed rate, f (mm/min)*Feed rate, f (mm/min) - 2234 Depth of cut, d (mm)*Depth of cut, d (mm)

- 21.48 % Weight of Sic*% Weight of Sic
+ 31.5 Spindle Speed, N (rpm)*Feed rate, f (mm/min)
+ 0.454 Spindle Speed, N (rpm)*Depth of cut, d (mm)
- 0.0598 Spindle Speed, N (rpm)*% Weight of Sic
+ 53751 Feed rate, f (mm/min)*Depth of cut, d (mm)
- 4917 Feed rate, f (mm/min)*% Weight of Sic
- 70.0 Depth of cut, d (mm)*% Weight of Sic

Table.4.2. Analysis of variance for Tool wear:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	0.158082	0.011292	40.56	0
Linear	4	0.154654	0.038664	138.89	0
Spindle Speed, N (rpm)	1	0.098102	0.098102	352.4	0
Feed rate, f (mm/min)	1	0.011285	0.011285	40.54	0
Depth of cut, d (mm)	1	0.009296	0.009296	33.39	0
% Weight of Sic	1	0.035971	0.035971	129.21	0
Square	4	0.001962	0.000491	1.76	0.201

Spindle Speed, N (rpm)*Spindle Speed, N (rpm)	1	0.000023	0.000023	0.08	0.778
Feed rate, f (mm/min)*Feed rate, f (mm/min)	1	0.000098	0.000098	0.35	0.564
Depth of cut, d (mm)*Depth of cut, d (mm)	1	0.000861	0.000861	3.09	0.104
% Weight of Sic*% Weight of Sic	1	0.000779	0.000779	2.8	0.12
2-Way Interaction	6	0.001466	0.000244	0.88	0.539
Spindle Speed, N (rpm)*Feed rate, f (mm/min)	1	0.0001	0.0001	0.36	0.56
Spindle Speed, N (rpm)*Depth of cut, d (mm)	1	0.00011	0.00011	0.4	0.541
Spindle Speed, N (rpm)*% Weight of Sic	1	0.000001	0.000001	0	0.953
Feed rate, f (mm/min)*Depth of cut, d (mm)	1	0.000042	0.000042	0.15	0.704
Feed rate, f (mm/min)*% Weight of Sic	1	0.000812	0.000812	2.92	0.113
Depth of cut, d (mm)*% Weight of Sic	1	0.0004	0.0004	1.44	0.254
Error	12	0.003341	0.000278		
Lack-of-Fit	10	0.003341	0.000334	*	*
Pure Error	2	0	0		

Total 26 0.161423

Regression equation for Tool wear in uncoded units:

Tool wear, VB = -0.143+ 0.000219 Spindle Speed, N (rpm)
(mm)
+ 5.27 Feed rate, f (mm/min)
- 0.086 Depth of cut, d (mm) - 0.0130 % Weight of Sic
+ 0.000000 Spindle Speed, N (rpm)*Spindle Speed, N (rp
m)
- 42.9 Feed rate, f (mm/min)*Feed rate, f (mm/min)
+ 0.0508 Depth of cut, d (mm)*Depth of cut, d (mm)
+ 0.000483 % Weight of Sic*% Weight of Sic
- 0.00100 Spindle Speed, N (rpm)*Feed rate, f (mm/min)
- 0.000021 Spindle Speed, N (rpm)*Depth of cut, d (mm)
- 0.000000 Spindle Speed, N (rpm)*% Weight of Sic
- 0.65 Feed rate, f (mm/min)*Depth of cut, d (mm)
+ 0.285 Feed rate, f (mm/min)*% Weight of Sic
+ 0.00400 Depth of cut, d (mm)*% Weight of Sic

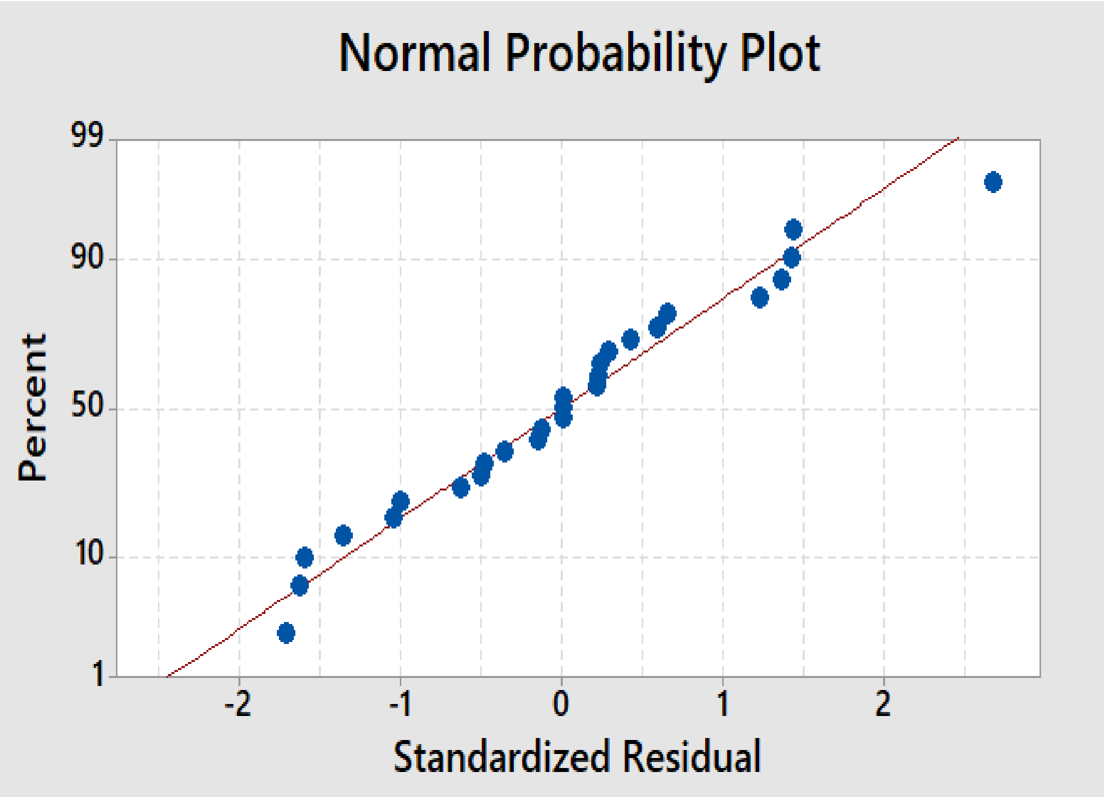
Graphs:

Normal probability plot for MRR AND Tool Wear:

The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality. The normal probability plot is a special case of the probability.

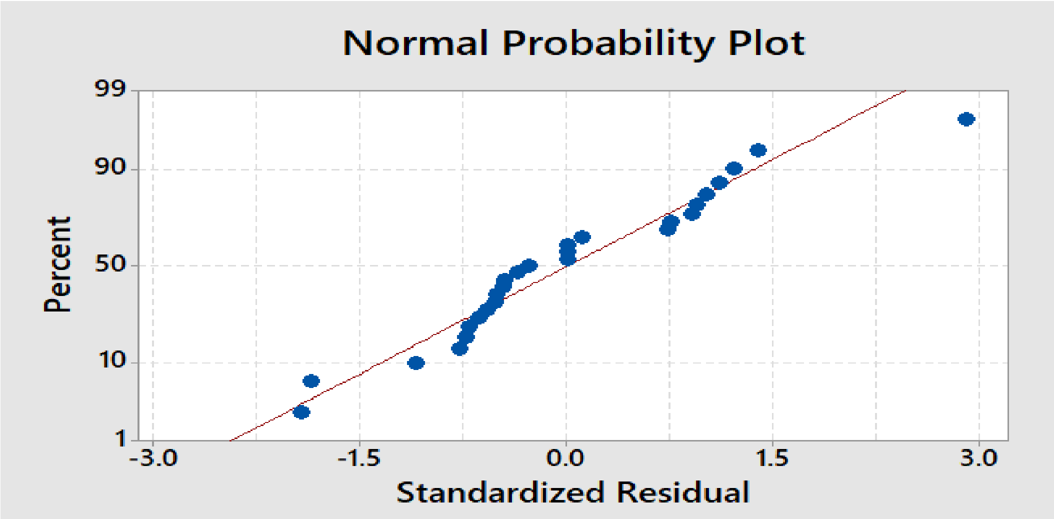
Pattern	**Indication**
Not a straight line	Non normality
Curve in the tails	Skewness
A point far away from the line	Outlier
Changing slope	Unidentified variable

Table.4.3. NORMAL PROBABILITY PLOT FOR TOOL WEAR:



From the above graph we have obtained a straight line which concludes that the data is normally distributed.

Table.4.4. NORMAL PROBABILITY PLOT FOR MRR:



From the above graph we have obtained a straight line which concludes that the data is normally distributed.

Minitab provides three types of residuals:

Regular residual: observed value - predicted value.

Standardized residual: $\frac{(\text{Observed value} - \text{Predicted value})}{\text{Predicted value}}$

The standardization eliminates the effect of the location of the data point with respect to the predictors or factors.

Studentized deleted residual: For the i^{th} data point, the formula follows the same expression as the standardized residual. However, the i^{th} fitted value and the standard deviation are calculated for the studentized deleted residual by deleting the i^{th} case in the analysis. Compared to the standardized residual, the studentized deleted residual becomes larger in the presence of an unusual data point.

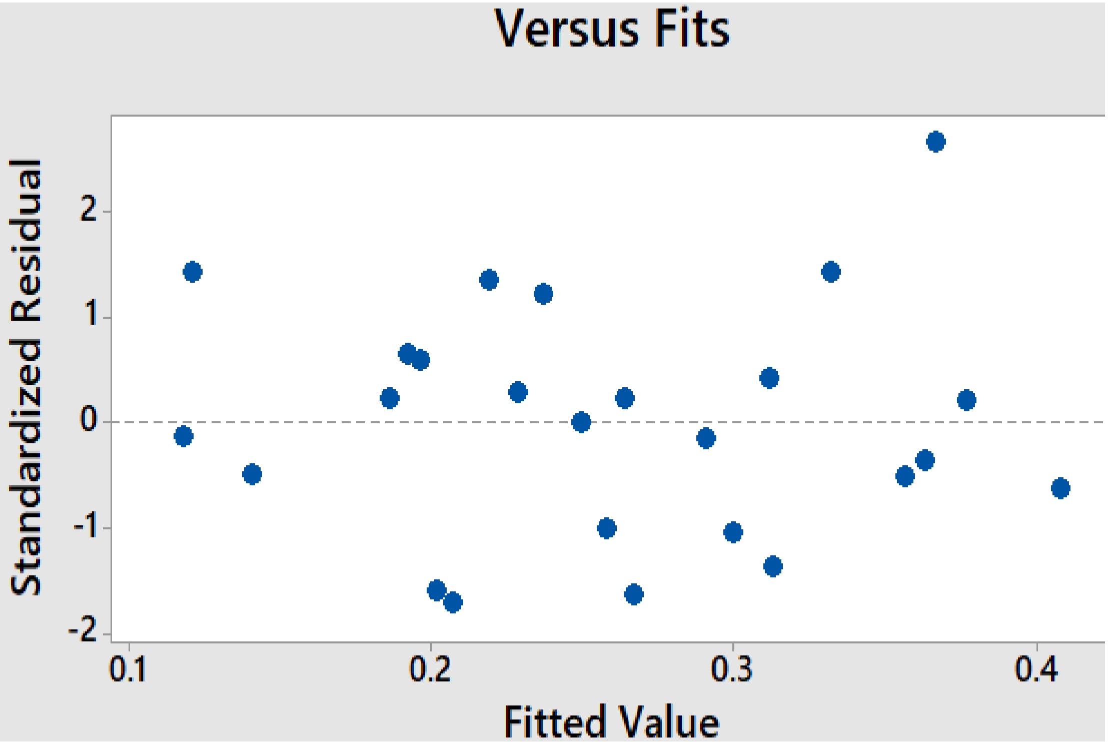
Standardized residual vs Fits plot for MRR and Tool Wear:

Graph indicates that the maximum variation of 0.1 to 0.5, which shows the high correlation that, exists between fitted values and observed values for tool wear.

Graph indicates that the maximum variation of 500 to 2500, which shows the high correlation that, exists between fitted values and observed values for MRR.

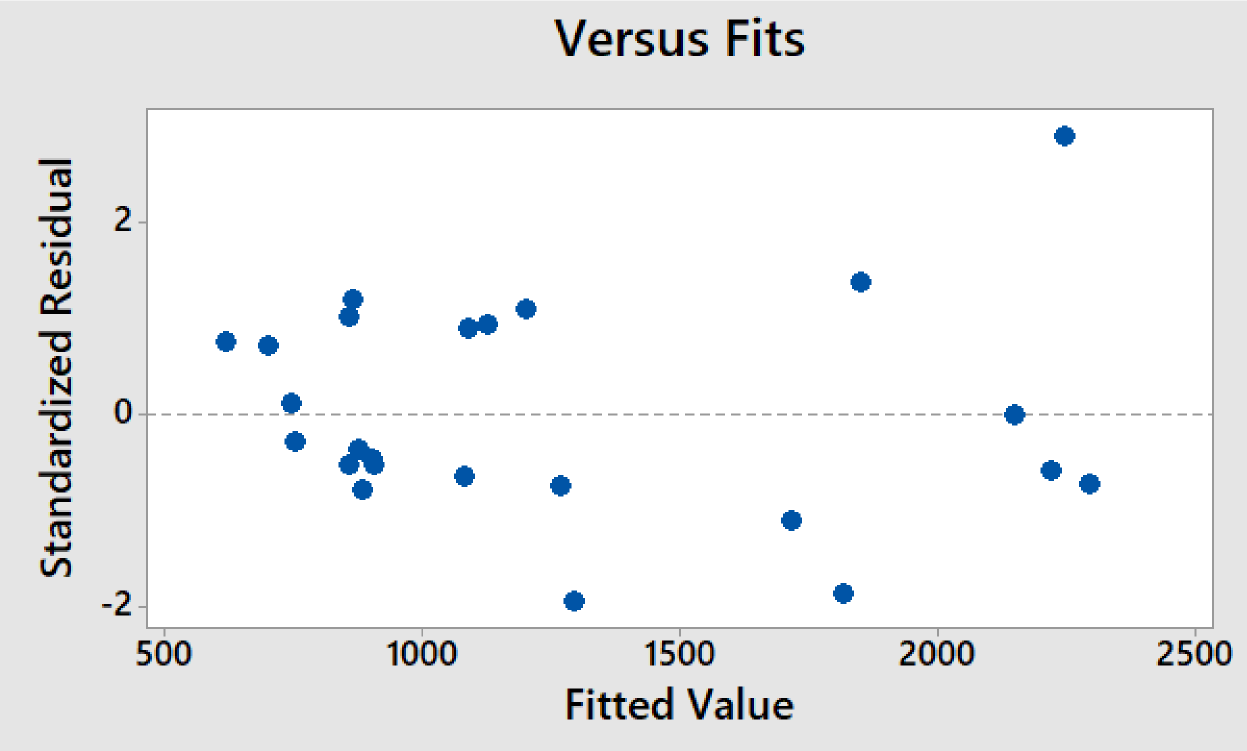
Pattern	**Indication**
Fanning/uneven spreading of residuals across fitted values	Non-constant variance
Curvilinear	A missing higher order term
A point far away from zero	An outlier
A point far away from the other points in the x-direction	An-influential point

PLOT FOR TOOL WEAR:



From the above graph we can observe that variability has remained same for all the fitted values, so the variability is equal all the way along. There also doesn't appear to be any curvature or any other indications that there a problem with the model.

PLOT FOR MRR:



From the above graph we can observe that variability has remained same for all the fitted values, so the variability is equal all the way along. There also doesn't appear to be any curvature or any other indications that there a problem with the model.

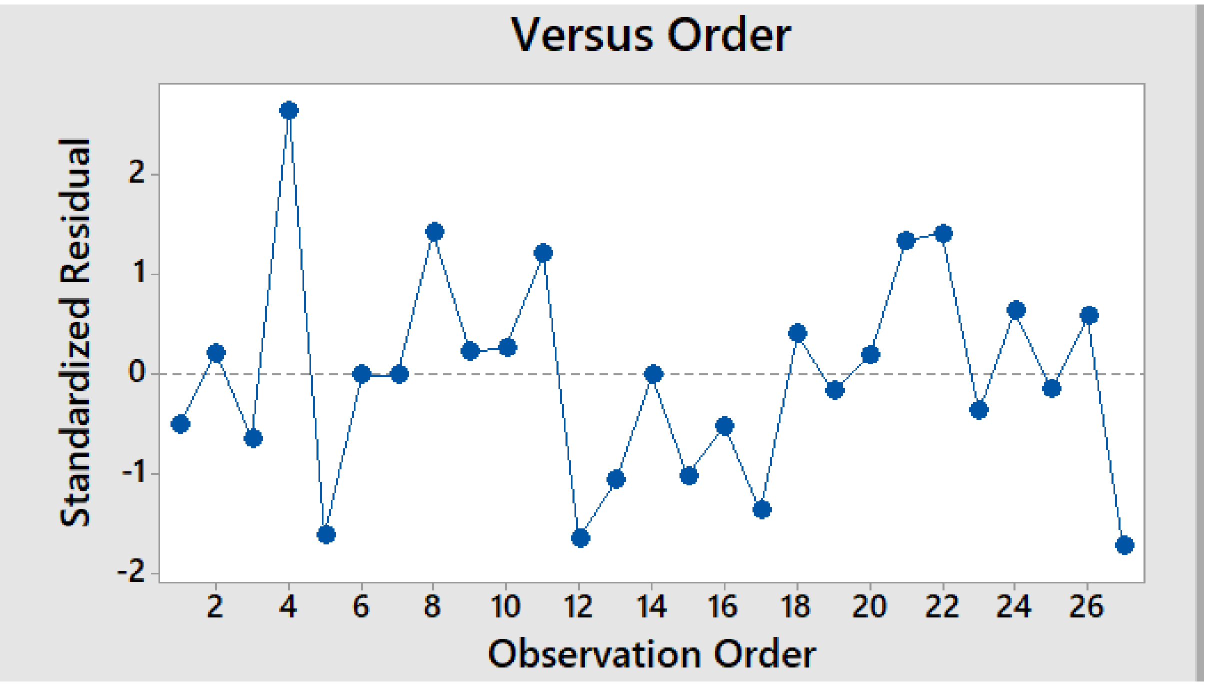
Residuals vs Order plot for MRR and Tool Wear:

This graph plots the residuals in the order of the corresponding observations. The plot is useful when the order of the observations may influence the results, which can occur when data are collected in a time sequence or in some other sequence. This plot can be particularly helpful in a designed experiment in which the runs are not randomized.

Correlation among residuals may be signified by:

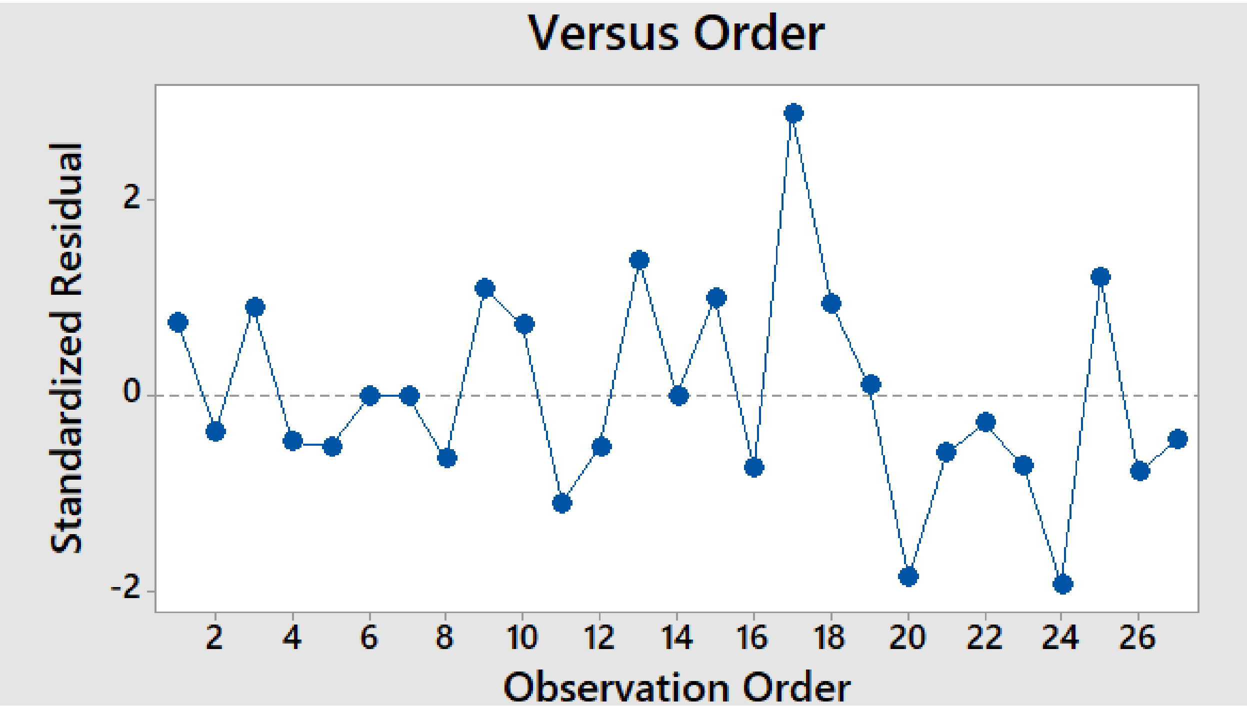
- An ascending or descending trend in the residuals
- Rapid changes in signs of adjacent residuals

PLOT FOR TOOL WEAR:



The above graph connects each experiments error (distance from the zero mean or zero error) with the following experiment and a line plot is obtained.

PLOT FOR MRR:



The above graph connects each experiments error (distance from the zero mean or zero error) with the following experiment and a line plot is obtained.

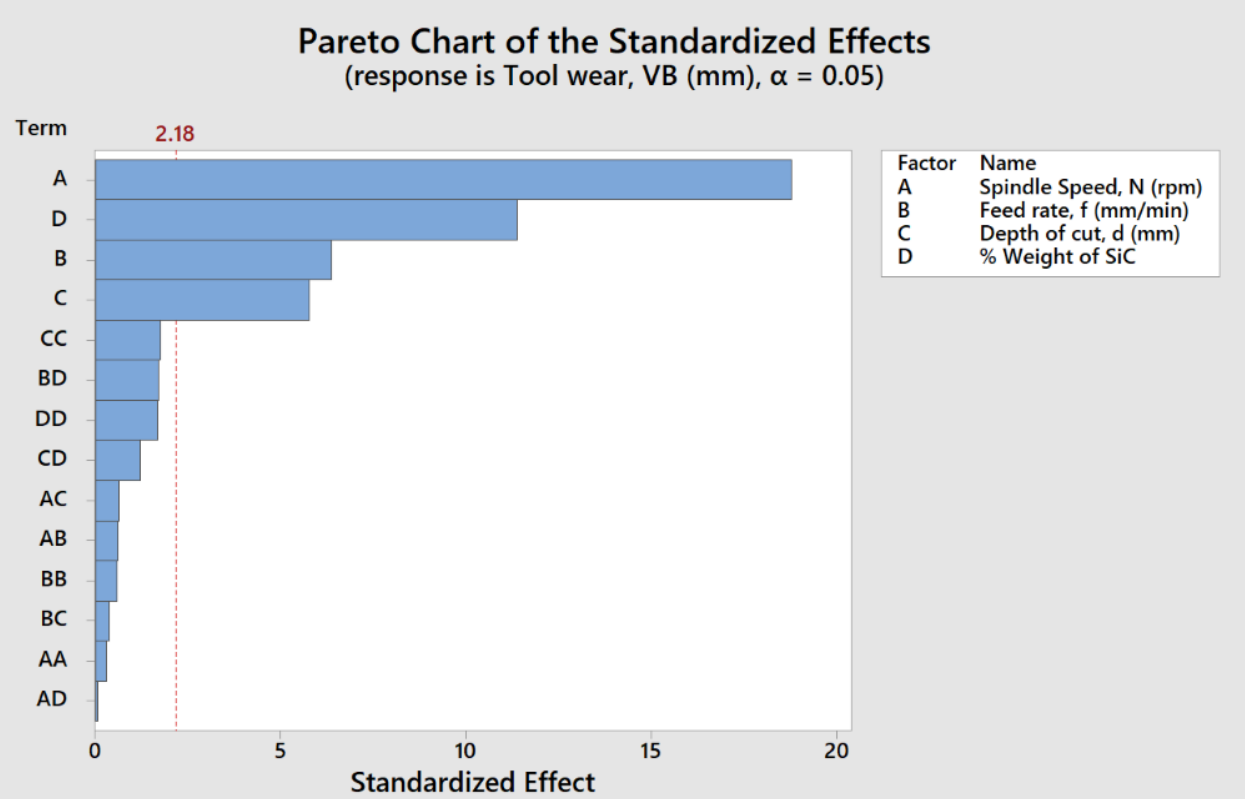
Pareto Chart of the Standardized effects:

A Pareto chart is a bar graph. The lengths of the bars represent frequency or cost (time or money), and are arranged with longest bars on the left or top and the shortest to the right or bottom. In this way the chart visually depicts which situations are more significant.

A Pareto Chart is used -

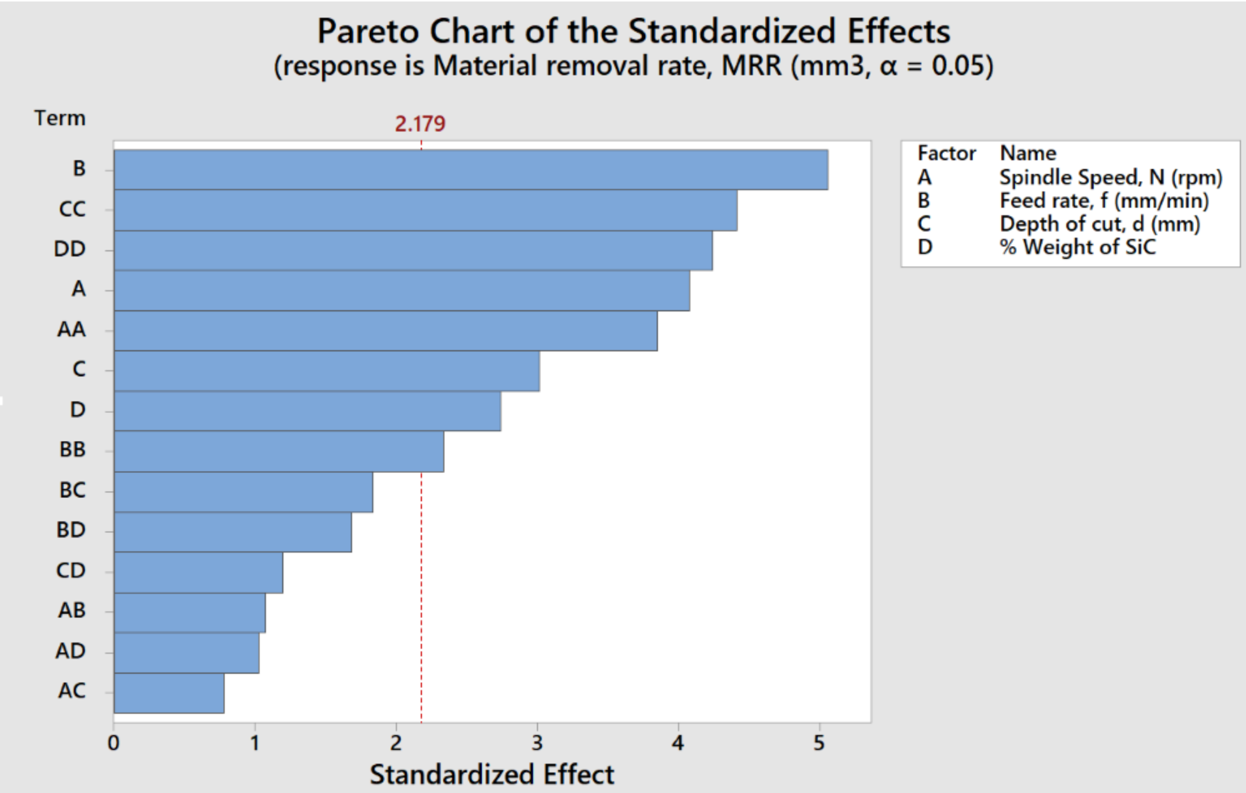
- When analyzing data about the frequency of problems or causes in a process.
- When there are many problems or causes and you want to focus on the most significant.
- When analyzing broad causes by looking at their specific components.
- When communicating with others about your data.

Table.4.5 a)PLOT FOR TOOL WEAR:



From the above pareto chart it is clear that the terms rightswards to the standardized effect(2.18) are more significant.

Table.4.5 b)PLOT FOR MRR:



From the above pareto chart it is clear that the terms rightswards to the standardized effect(2.179) are more significant.

4.4.Histogram:

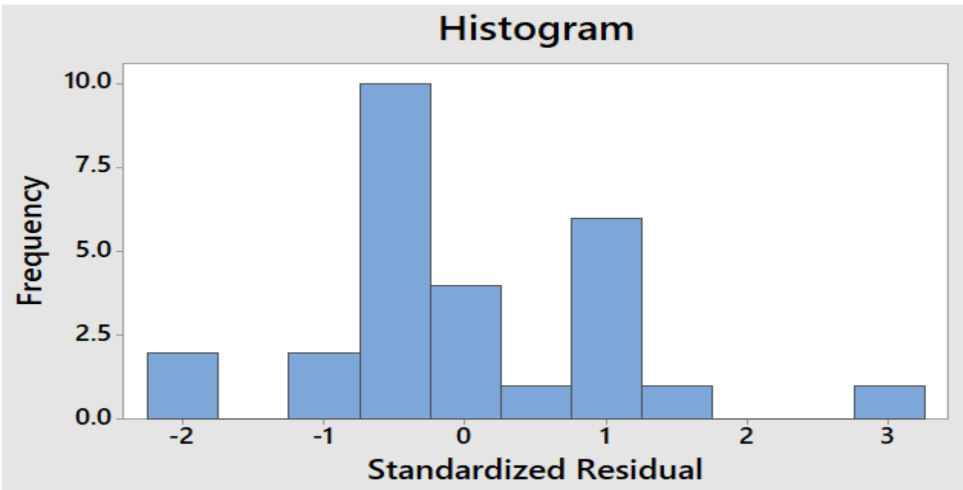
A frequency distribution shows how often each different value in a set of data occurs. A histogram is the most commonly used graph to show frequency distributions. It looks very much like a bar chart, but there are important differences between them.

A Histogram is used -

- When the data are numerical.
- When you want to see the shape of the data's distribution, especially when determining whether the output of a process is distributed approximately normally.

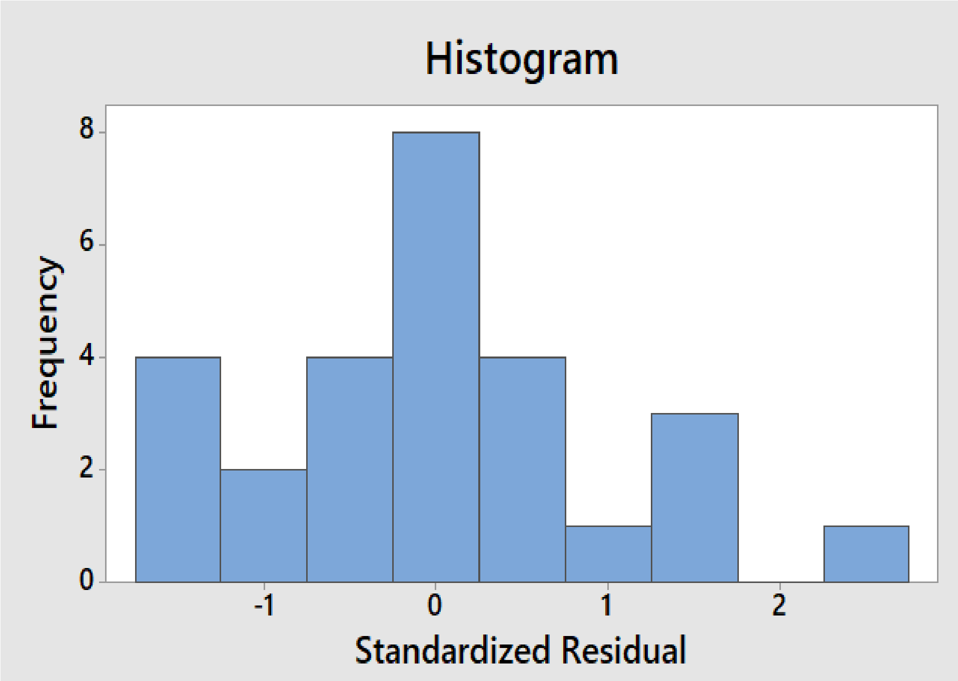
- When analyzing whether a process can meet the customer's requirements.
- When analyzing what the output from a supplier's process looks like.
- When seeing whether a process change has occurred from one time period to another.
- When determining whether the outputs of two or more processes are different.
- When you wish to communicate the distribution of data quickly and easily to others.

Table.4.6. a) PLOT FOR MRR:



From the above histogram we can observe that we have the highest frequency of residuals(error) in the region – [-0.75,-0.25].

Table.4.6. b) PLOT FOR TOOL WEAR:



From the above histogram we can observe that we have the highest frequency of residuals(error) around the zero-mean region.

4.6.Predicted and experimental values:

Material removal rate:

The material removal rate is predicted by using the regression equation obtained from Minitab.

The equation is as follows:

Material removal rate(predicted) = -13254 + 5.51*n + 141290*f + 5619*d + 725*p - 0.00195*n*n - 2953679*f*f - 2234*d*d - 21.48*p*p + 31.5*f*n + 0.454*n*d - 0.0598*n*p + 53751*f*d - 4917*f*p - 70*d*p

Where,

n – spindle speed in rpm

f – feed rate in mm/min

d – depth of cut in mm

p – percentage of Sic

MRR ACTUAL(MM3/MIN)	MRR PREDICETD(MM3/MIN)	%ERROR
759.49	611.81	19.44462732
805.97	871.658	-8.150179287
1258.8	1079.53	14.24134096
812.61	894.298	-10.05254673
756.3	851.868	-12.63625545
2148.9	2143.583	0.247428917
2148.9	2143.583	0.247428917
956.3	1072.81	-12.18341525
1406.3	1193.45	15.13546185
834.45	690.533	17.24692911
1506.3	1712.398	-13.68240058
805.97	895.258	-11.07832798
2111.1	1846.633	12.52745014
2148.9	2143.583	0.247428917
1043.5	848.468	18.69017729
1126	1259.073	-11.81820604
2201.7	2241.493	-1.807
1303.6	1119.458	14.12565204
762.71	733.768	3.794627054
1463.4	1810.348	-23.70835042
2109.4	2218.873	-5.189769603

698.82	746.458	-6.816919951
2160	2289.937	-6.015601852
925.98	1286.973	-38.98496728
1088.7	859.633	21.04041517
734.13	875.448	-19.24972416
812.61	895.349	-10.18188307

Table.4.7. a) LINE PLOT FOR MRR:

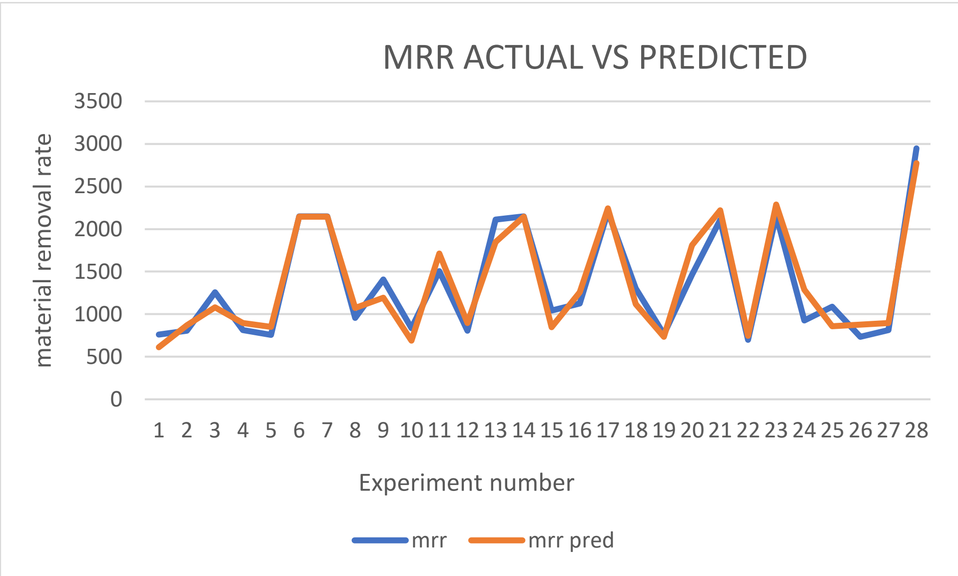
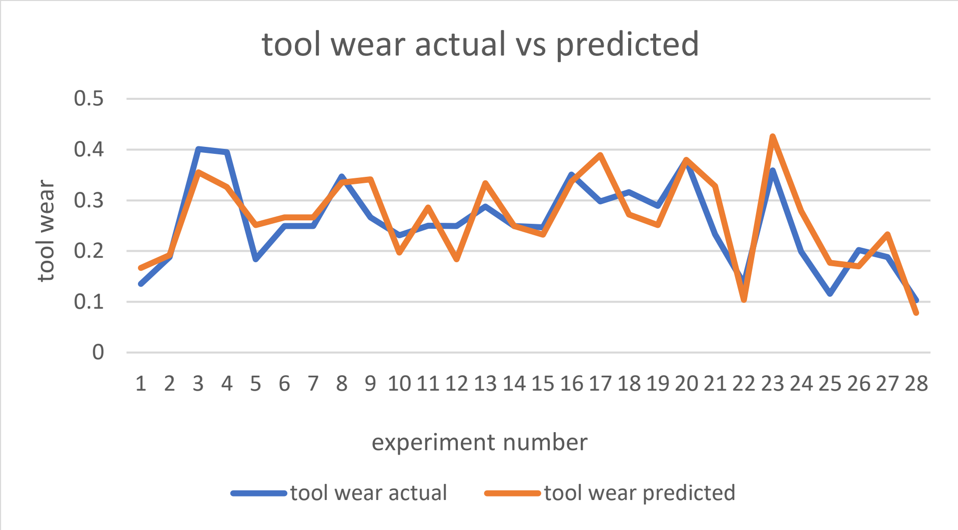


Table.4.7. b) LINE PLOT FORTOOL WEAR:



The tool wear is predicted by using the regression equation obtained from Minitab.

The equation is as follows:

Tool wear (predicted) = -0.143 + 0.000219*n + 5.27*f - 0.086*d - 0.013*p + 42.9*f*f + 0.0508*d*d + 0.000483*p - 0.001*n*f - 0.000021*n*d - 0.65*f*d + 0.285*f*p + 0.004*d*p

Where,

n – spindle speed in rpm

f – feed rate in mm/min

d – depth of cut in mm

p – percentage of Sic

TOOL WEAR ACTUAL(MM)	TOOL WEAR PREDICTED(MM)	%ERROR
0.135	0.167	-23.7037037
0.188	0.192	-2.127659574

0.401	0.355	11.4713217
0.395	0.326	17.46835443
0.184	0.251	-36.41304348
0.249	0.266	-6.827309237
0.249	0.266	-6.827309237
0.347	0.335	3.458213256
0.266	0.341	-28.19548872
0.231	0.197	14.71861472
0.25	0.286	-14.4
0.249	0.184	26.10441767
0.288	0.334	-15.97222222
0.249	0.249	0
0.247	0.232	6.072874494
0.351	0.337	3.988603989
0.298	0.389	-30.53691275
0.316	0.272	13.92405063
0.289	0.251	13.14878893
0.379	0.38	-0.263852243
0.233	0.328	-40.77253219
0.136	0.104	23.52941176
0.359	0.426	-18.66295265
0.199	0.279	-40.20100503
0.116	0.177	-52.5862069

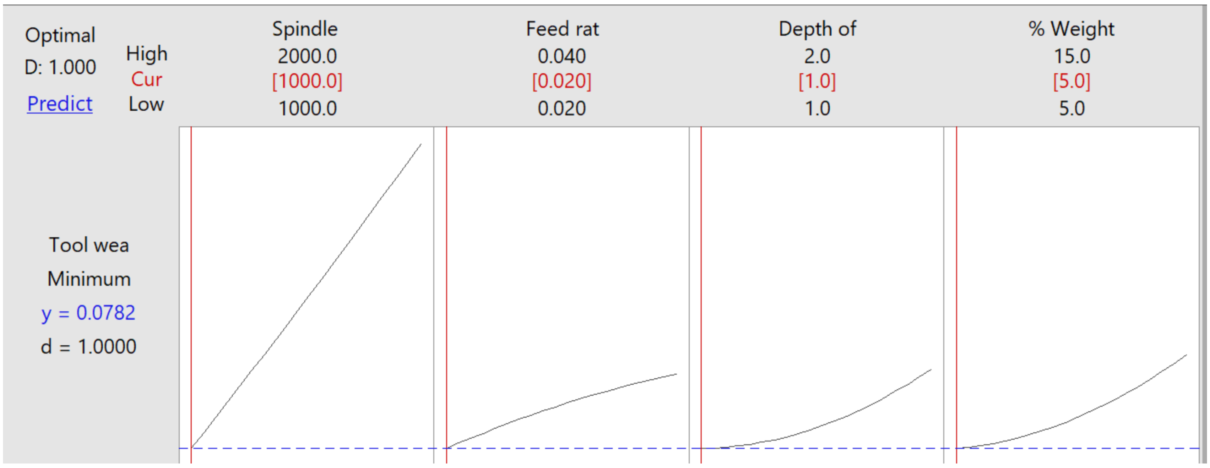
0.202	0.17	15.84158416
0.188	0.233	-23.93617021

4.5.Optimization Plot:

A Minitab Response Optimizer tool shows how different experimental settings affect the predicted responses for factorial, response surface, and mixture designs. Minitab calculates an optimal solution and draws the plot. The optimal solution serves as the starting point for the plot. This optimization plot allows to interactively changing the input variable settings to perform sensitivity analysis and possibly improve the initial solution.

Table.4.8. a) Optimization of tool wear:

During the machining process tool wear should be as minimum as possible , so the tool wear is minimized and the following optimized value of tool wear is shown below:



From the above data it is clear that the tool wear is minimum when the input factors are

Spindle speed (RPM) = 1000

Feed rate (F) = 0.02mm/min

Depth of cut (D) = 1.0mm

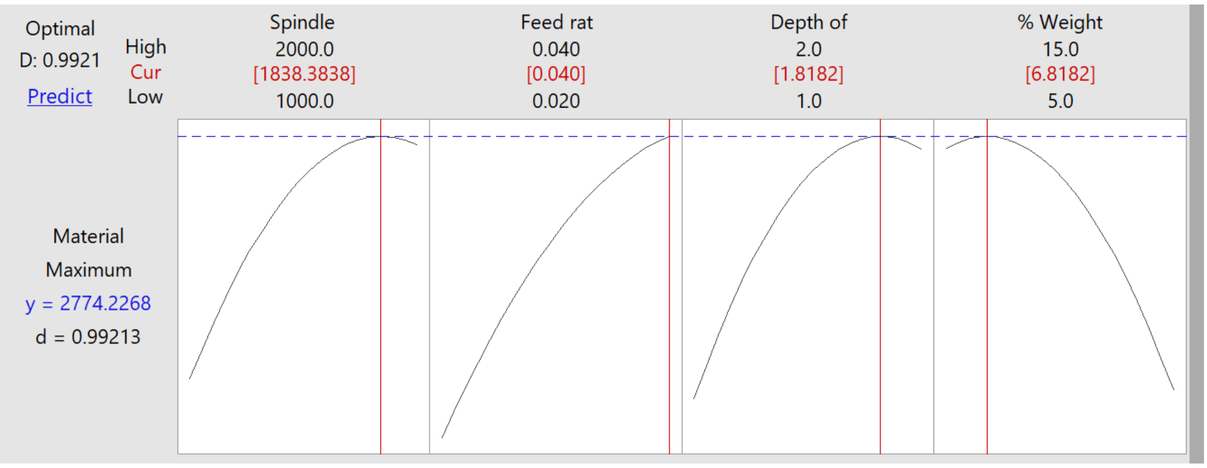
% weight of Sic = 5

CONFIRMATION TABLE

spindle speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	%weight of Sic	Tool wear (mm)
1000	0.02	1	5	0.0782
1000	0.02	1	5	0.103

Table.4.8. b)optimization of material removal rate:

During the machining process material removal rate should be as maximum as possible , so the material removal rate is maximized and the following optimized value of material removal rate is shown below:



From the above data maximized material removal rate will be obtained when input parameters are

Spindle speed (RPM) = 1838.3838

Feed rate (F) = 0.04mm/min

Depth of cut (D) = 1.818mm

% weight of Sic = 6.818

CONFIRMATION TABLE

spindle speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	%weight of Sic	Material removal rate (mm3/min)
1838.3838	0.04	1.818	6.818	2774.2268
1838.3838	0.04	1.818	6.818	2947.615

4.6. CONCLUSION:

RSM based analysis was applied with different cutting parameter settings for predicting the machinability characteristics such as tool wear and MRR in the end milling of Al7075/Al2O3/SiC hybrid composites by adopting specific weightages for the characteristics. As the process requirements are varied, the weightages used in the RSM analysis are also varied. From the analysis, the best combination of values for simultaneously minimizing the surface roughness, tool wear, cutting force and maximizing MRR was found. The best combination of parameters is noted as spindle speed of 1000 rpm, feed of 0.02 mm/rev, depth of cut of 1 mm and 5% of Sic produce best tool wear outcome and a spindle speed of 1838 rpm, feed of 0.04 mm/rev, depth of cut of 1.81 mm and 6.81 % of Sic for material removal rate. Confirmation tests validated the improvement in performance measures. From the ANOVA, it is noted that spindle speed and weight percentage of Sic are the most significant factors affecting the machinability of hybrid composites. The increase in feed rate increases the thrust force and torque, leading to greater tool wear and higher power consumption. It is possible to optimize any specific performance measure such that the other performance measures meet the minimum requirement.

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