A STUDY OF THE IMPACT OF MULTIPLE DRILLING PARAMETERS ON SURFACE ROUGHNESS, MATERIAL REMOVAL RATE AND TOOL WEAR WHILE DRILLING Al 6063 APPLYING TAGUCHI TECHNIQUE

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By

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CERTIFICATE

It is certified that **Md Shahrukh Khan** (Enrollment No. 2000103058) has carried out the research work presented in this dissertation entitled "**A study of the impact of multiple drilling parameters on surface roughness, material removal rate and tool wear while drilling Al 6063 applying Taguchi technique"** for the award of **Master of Technology** from **Integral University, Lucknow** under our supervision. The dissertation embodies result of original work and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any degree to the candidate or to anybody else from this or any other university/Institution.

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DECLARATION

I hereby declare that the dissertation titled "**A study of the impact of multiple drilling parameters on surface roughness, material removal rate and tool wear while drilling Al 6063 applying Taguchi technique**" is an authentic record of the research work carried out by me under the supervision of Dr. Shahnawaz Alam, Department of Mechanical Engineering, for the period from 2020 to 2022 at Integral University, Lucknow. No part of this dissertation has been presented elsewhere for any other degree or diploma earlier.

I declare that I have faithfully acknowledged and referred to the works of other researchers wherever their published works have been cited in the dissertation. I further certify that I have not willfully taken other's work, paragraph, text, data, results, tables, figures etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc. or available at websites without their permission, and have not included those in this M. Tech. dissertation citing as my own work.

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LIST OF ABBREVIATION

CNC	Computer Numerical Control
MRR	Material Removal Rate
DOE	Design of Experiment
R_a	Surface Roughness
ANOVA	Analysis of Variance
S/N	Signal-to-Noise
RPM	Revolution per minute
HSS	High Speed Steel
dB	Decibel
DF	Degree of Freedom

ABSTRACT

The goal of this project is to see how different drilling parameters like spindle speed (600, 900, 1400 revolution per minute), feed rate (0.10, 0.16, 0.22 mm per revolution) and drill tool diameter (6mm and 8 mm) affect the Surface roughness, Material removal rate and Tool wear while drilling Al 6063 alloy with an HSS spiral drill using Taguchi method. The impact of different drilling settings on the accuracy of the drilled hole is analyzed using S/N (signal-to-noise) ratio, orthogonal arrays of Taguchi, regression analysis, and analysis of variance (ANOVA).

CNC Milling Machine is used to perform a number of experiments with the help of L_{18} orthogonal arrays of Taguchi. MINITAB 19, a commercial software tool, is used to collect and evaluate the results of the experiments. For establishing a correlation between the selected input parameters and the quality aspects of the holes made, linear regression equations are used. The experimental data are compared to the expected values, which are quite similar.

CHAPTER- 1

INTRODUCTION

1.1 INTRODUCTION

In today's modern industries, the primary goal of engineers is to produce items at a lower cost while maintaining excellent quality in a short period of time. In a production process, engineers are encountering two very basic practical issues. The first one is to identify the best combinations of input parameters which will result in the required quality of the product (fulfill essential requirements), and the other one is to increase production efficiency with the existing resources. Although advanced material cutting technologies have been developed in industrial sectors, but traditional drilling is still among the most practiced mechanical operations in the aerospace, aircraft, and automotive industries.

Making holes is among the most essential requirements in the industrial procedure. Drilling is the most popular and important hole-making method, comprising almost one third of all metal cutting operations. Drilling is the process of removing a volume of metal from a workpiece by using an instrument called "a drill" to cut a cylindrical hole. Based on the material type, the hole's shape, the counting of samples, and the period of time it takes in finishing the work, several instruments and procedures are used for drilling. It is most commonly used in removal of material and as a pre-processing step for a variety of operations like spot facing, counter sinking, and reaming etc. A multipoint fluted end cutting tool is used to create or extend a hole at the time of cutting operation. Material is eliminated mostly in the chips shape which passes with drill's fluted shank as it rotates and penetrates into the work material. Coolants are also used sometimes during the operation as per the requirement.

L_{18} orthogonal array of Taguchi is utilized to conduct the experiment. The significant drilling parameters are selected as rotation speed, rate of feeding and diameter of the drilling tool respectively. The best combination of all the input parameters is selected to reduce the values of the performance attributes which are mentioned above. For the optimization of these parameters, Taguchi optimization method is used. ANOVA is also used to identify the extremely effective input parameter(s) which lead to a good quality product. Point angle and Helix angle are kept standard as 118 degree and 30 degrees respectively.

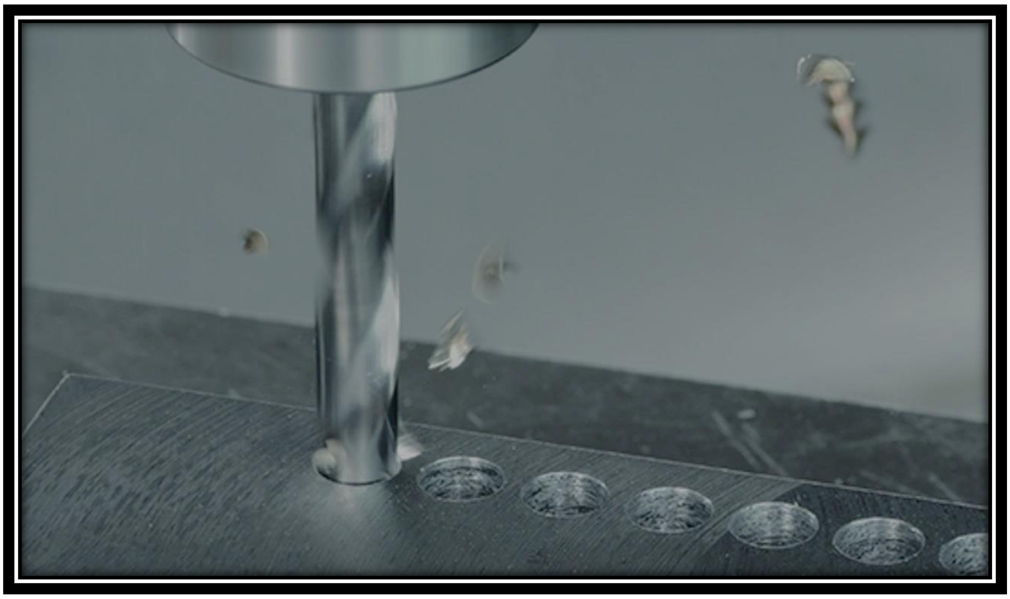

Figure 1.1: Holes made by drilling process

1.2 DRILLING OPERATION

To use a drill bit to make a hole with a cylindrical cross-section out of solid materials is called drilling. A drill is often a rotating tool for cutting with several points. The drill is rotated at hundreds or even thousands of Revolutions while being forced on the object. As an outcome, during cutting, the cutting tip is pressed up against the workpiece, clearing chips from the hole.

One of the essential mechanical equipment in the workshop is the drilling machine. According to one estimate, drilling accounts for 75 percent of all metal-cutting material removed throughout the machining process.

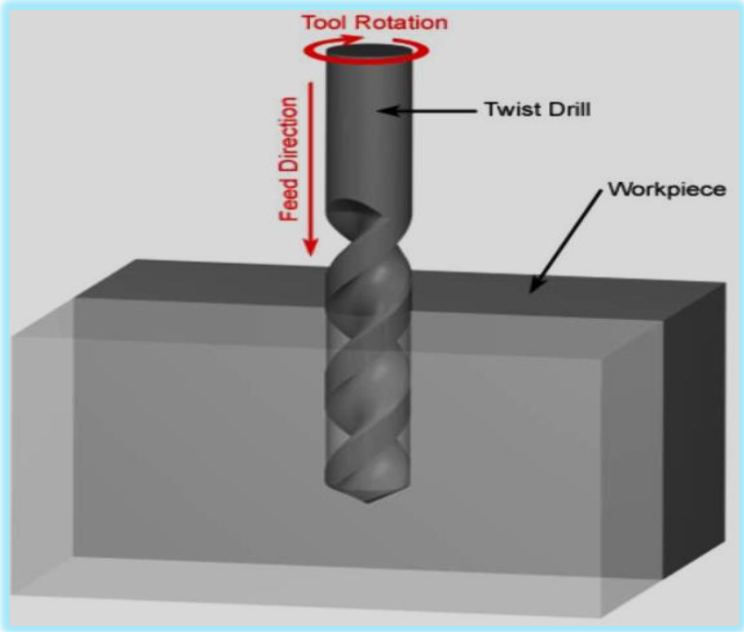

Figure 1.2: Representation of terms used in Drilling Operation

1.3 DIFFERENT TYPES OF OPERATIONS PERFORMED ON A DRILLING MACHINARY

Following are the different types of operation performed on a drilling machine:

A. Drilling (As discussed above)
B. Boring
C. Spot Facing
D. Tapping
E. Counterboring
F. Reaming
G. Countersinking

B. Boring Operation: Boring is a kind of drilling operation in which the diameter of a previously drilled hole is increased.

C. Spot Facing: The surface around the hole is squared in the spot facing. That surface is also finished during this process. A spot facing tool is used for this operation.

D. Tapping Operation: In tapping, a tap is utilized to make internal threads. Which means tap acts like a cutting tool inside the tapping.

E. Counterboring: The hole's end is enlarged cylindrically during counterboring. A counterbore is a tool used in the counterboring process.

F. Reaming: Reaming is used to get the hole to the required size. This method also allows the hole's internal surface to be properly finished. Reaming is done with a reamer. A reamer is a cutting tool with multiple points.

G. Countersinking: Countersinking is commonly used to create a cone-shaped extension at the hole's end. The conical surface may have a 60-to-90-degree angle.

1.4 TYPES OF DRILL TOOLS

Drilling tools come in a variety of shapes and sizes. Always wear safety glasses, gloves, and a dust mask, regardless of the tool you're using. Of course, you should only utilize high-quality equipment. So, let's have a look at the most popular drill types, which are as follows:

I. **Hand drill:** A hand drill is the most basic type of drill. They're great for pre-drilling holes before inserting screws. Simply turn the drill left and right until the tip of the drill is embedded in the wood. Then continue to turn the drill to the right until you reach the desired depth. These tools are great because they don't require any electricity and are very simple to use.

II. **Hand drill and brace:** Despite the fact that we are in the twenty-first century, people still use these tools. They are far quieter than electric drills and allow for precise hole drilling. You can use them on wood and soft materials, but they can't produce deep holes even then. There are additional bits designed specifically for this sort of drilling instrument that provide increased precision.

III. **Standard electric drill:** These drills are ideal for the majority of repair operations. They enable you to fix heavy objects by drilling holes and screwing them together. Electric drills are divided into two categories: battery-powered and cable-powered drills.

Because you don't have to be near the power supply all of the time, the first ones are fine. There are also no cables to get in the way. Drills powered by cable, on the other hand, are usually significantly more powerful.

IV. **Hammer drill:** Hammer drills are comparable to conventional drills, but they have a "hammering" aspect as well. They're ideal for drilling through hard materials like concrete and stone. Many models let you alternate between pounding and turning, or even do both at once.

V. **Benchtop drill press:** These units are a little tough for beginners to use, but they can be extremely useful for skilled workers. The main benefit of these drills is that they allow you to drill extremely precise holes. They also provide a lot of power and can be utilized for a variety of materials.

1.5 ADVANTAGES OF DRILLING PROCESS

- All materials can be machined.
- Good speed.
- Ease of operation.
- High manageability.
- Maintaining cost is less.
- High output rate.

1.6 DISADVANTAGES OF DRILLING PROCESS

- Limited size workpiece.
- Oversized hole.
- High equipment cost.
- Tool wear.
- Breaking of drill bits.
- More wastage of material in the form of chips.
- Drilling holes may require further operations and machining.
- Noisy operation.

1.7 APPLICATIONS OR USES OF DRILLING PROCESS

Some applications of drilling process are discussed below:

- Almost all industrial industries use drilling equipment to create the necessary holes in the workpiece.
- Additionally, this is employed in carpentry activities to drill holes in wood and fix wooden structures.
- Usually employed in building projects, glassworks etc.
- Screwing and fixing are done with hand drills or portable drills. Oil / water wells can be drilled using drilling equipment. Builders, electricians, and plumbers all use electric pistol handle drills for basic masonry work. Carpenters utilise hammer drills specifically to cut and attach wood components.
- In the construction, woodworking, and metalworking sectors, drills are utilised in a wide range of applications. To cut holes in materials and walls for our domestic needs, we

utilise a tiny drill. These are offered in a variety of sizes and power levels. One of the earliest everyday equipment, drills have been around since the start of the industrial era.

- ❖ This machine tool can be useful in a wide range of industries since it can carry out a wide range of operations including reaming, boring, counter-boring, tapping, countersinking and many more.
- ❖ Highly precise drilling equipment is currently thought to be among the most crucial instruments in the metal sector. It's due to the fact that such a large range of production operations involving various kinds of materials usually call for accurate drilling.

Following are some precautions which should be considered when the drilling equipment is used:

a) A powerful and strong drill press is required to drill a hole through the workpiece; else, the cutting force may deform the parts. Directionally stable drill feeding system is required.

b) It must ensure that the spindle, adapter, and tool axes coincide in order to prevent any errors.

c) Use precisely ground drills to ensure that both cutting edges generate uniform chips; otherwise, uneven pressures could cause the tool to be deflected during machining.

d) The workpiece must be held firmly in order to prevent:

Wrong Shape,

Burrs,

and location error in the hole.

e) Never eliminate chips manually; always use a brush.

f) For the material being drilled, use the appropriate cutting fluid. Find out from the shop personnel which fluid is best for the product you are cutting.

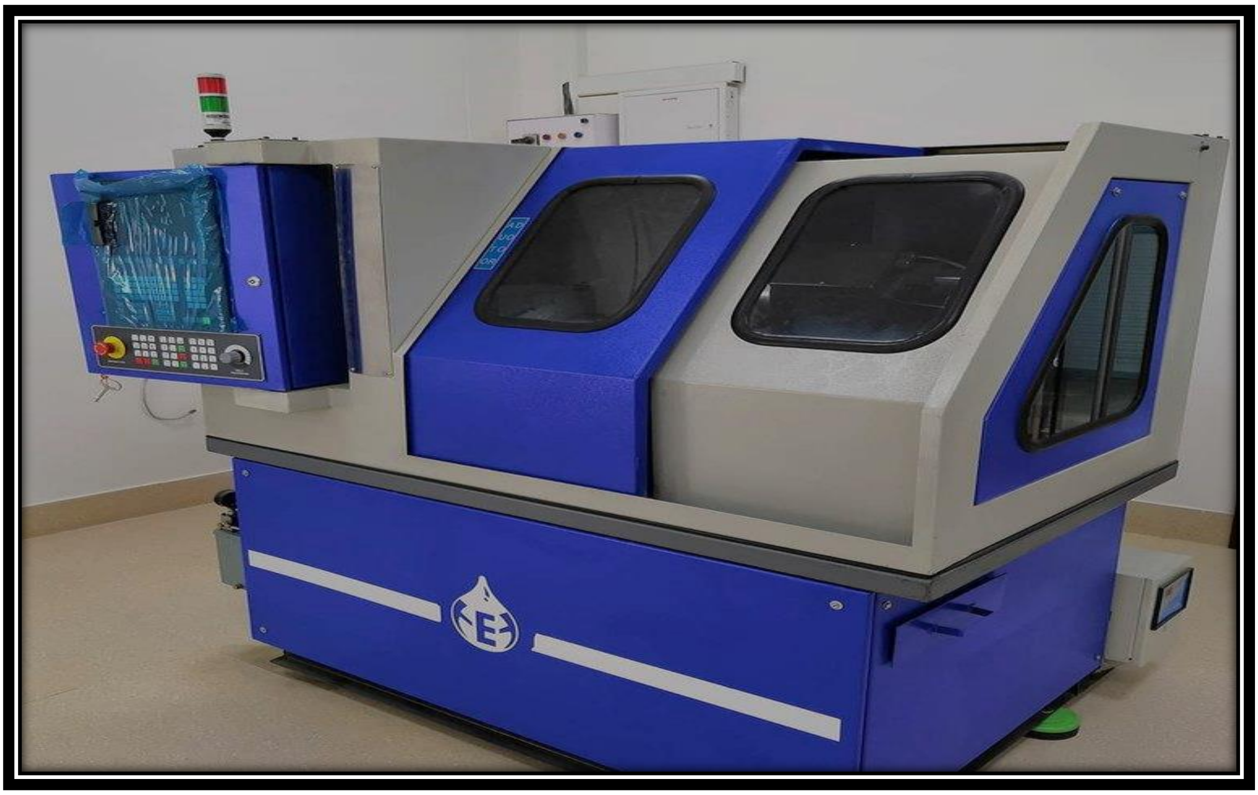

Figure 1.3: Experimental Setup

CHAPTER – 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

T. Karthikeya Sharma [2014] In this research, drilling of the Al2014 alloy has been done using rotation speed, angle of point, and rate of feeding as the input process parameters. The outcomes are hole diameter and hole surface roughness at the entry and exit of the hole. To get good-quality holes when drilling Al 2014 alloy, the drilling settings are adjusted in relation to a number of performances. Using the Taguchi approach, the parameters were optimized. It was determined that the best combination of drilling parameters to generate a high value of s/n ratios of hole roughness was a spindle speed of 300 rpm, point angle and helix angle of 1300/200, and a feed rate of 0.15 mm/rev. Additionally, it was determined that the ideal combination of machining parameters which provided a high value of s/n ratios of Hole Diameter was a rotation speed of 200 rpm, angle of point & angle of helix of 900/150, and a rate of feeding of 0.36 mm per rev.

Pradeep Kumar Jeyaraj [2018] In this work, the Taguchi technique was used to investigate how the drilling parameters affected the surface roughness, tool wear, material removal rate, and hole diameter error when drilling OHNS. Using a fundamental Signal-to-Noise (S/N) ratio methodology, regression analysis, and analysis of variance (ANOVA), drilling results were analyzed.

Gurcan Samtas [2014] To achieve the best surface roughness and roundness error values when drilling AISI 316 austenitic stainless steel with treated and untreated drills, the Taguchi method was used in this work to optimize drilling parameters. The rotation speed (78.11 percent) and rate of feeding (35.352 percent) had substantial influence on the roughness of the surface and the roundness error respectively in the experimental trials carried out using orthogonal arrays described by Taguchi. Surface roughness quality losses (52.36%) for ideal combinations (Ct = CT, V = 14 m/min, f = 0.08 mm/rev) were almost equal to half of those at experimental combinations. Similarly, the roundness error quality losses for optimal combinations become 51.76 percent. Considering optimal process parameters, it was determined that the ideal values for surface roughness and roundness error were 1.77 mm and 5.60 mm, respectively. In order to drill AISI 316 stainless steel efficiently and also at the lowest possible cost, the Taguchi method was successfully used to identify the best combinations of drilling parameters. Further studies could take into account additional variables that affect surface roughness and roundness error, such as drilling depth, lubricant used, angle of point and angle of helix, and cryogenic treatments at various soaking times (e.g., 4, 8, 12, 36, 48 h, and so on) and cryogenic temperatures (e.g., -70, -125, -150 °C).

D. Suneel [2016] In this study, the Taguchi method of Design of experiment is used to optimize the surface roughness when turning Inconel 718 with a TiCN-Al2O3 coated cemented carbide insert. The 300-rpm speed, 0.15 mm/rev feed rate, and 0.3 mm depth of cut were the controlling variables in the surface roughness optimization process. The confirmation test and analysis of variance were used to validate the efficacy of this strategy (ANOVA). The findings of measuring the ideal combination's predicted and experimental S/N ratios and surface roughness of ideal combination were very similar.

A. Thanikasalam [2016] Several deep hole drilling techniques are utilized to make deep holes with good surface finish and low roundness error. Gun drilling is one such process to drill high quality deep holes that has gained significant importance in industries. Deep hole drilling of AISI 1045 steel and the impact of machining parameters on roughness of the surface and roundness error of the drilled holes were studied. Taguchi's orthogonal array and ANOVA are utilized in experimental layout and to analyze the process parameters, respectively. It has been found that the rate of feed has greater impact in affecting the quality characteristics. 2200 RPM rotation speed and 80 mm/min rate of feed are the perfect values in deep-hole drilling of AISI 1045 steel within the selected limits.

M. Meignanamoorthy [2016] The goal of the present research is to validate the impact of drilling parameters in drilling of AA6063 in a CNC lathe by utilizing HSS drill bit. The input parameters known as the rotation speed, rate of feed and cutting depth are wide-ranging to experiment their influence on the rate of material removal (MRR). The trials were done using the L_{16} orthogonal array of Taguchi. Consequence of quality of CNC drilling process was found by Design of Experiments (DOE) and analysis of variance (ANOVA). The investigations expose that the rate of material removal is directly impacted with the rotating speed of the tool , rate of feed and cutting depth. It was found that the MRR increase and increases with related to rate of feed, rotation speed and regularly for each cutting depth and also monitor the machining time.

Sudha Kumari [2013] In this study, the topic of surface roughness reduction while drilling stainless steel SS304 utilizing HSS drill is discussed. In this investigation, drilling of SS304 was combined with the delivery of SiC abrasive with grain sizes of 650 and 1250 mesh using an abrasive slurry system. Abrasives are utilized for more than just cooling; they also improve surface finish, MRR, and lesser tool wear. On a universal milling machine, experiments were carried out. The Response Surface Methodology (RSM) is used to carry out experimental planning. To determine the major control factors and the percentage contributions of each control component, analysis of variance is used. Various performance parameters for surface roughness were used to optimize the drilling settings, including spindle speed, feed rate, slurry concentration, and mesh size. The outcome demonstrates that the feed rate and spindle speed are indeed the two most important variables that determine surface roughness, and this method efficiently enhances drilling efficiency.

A. Parthiban [2018] The primary goal of this experiment is to develop the mathematical modeling and to find out the optimized combination of rotation speed and rate of feed for 6mm and 8mm diameter of the tool. so that the MRR increases for drilling of AA 6061 Aluminium Alloy. The conclusions are made as follows:

In the drilling process, the experimental work carried out by full factorial design, Optimal Parametric combinations were found out. Design of Experiment (DOE) approach method is establishing relations with Input and response parameters.

Through the Response surface graphs, it can be seen that High speed and high rate of feed to achieve Maximum MRR for drilling of AA 6061 Aluminium alloy for both 6 mm and 8 mm drill diameter.

S. Puneeth [2017] By employing the method to identify and link Taguchi technological elements for the effectiveness of the machining operation, an effort is made to execute experimental study on Aluminium alloys. A systematic approach to experiment design and analysis is the Taguchi technique, a potent statistical tool. This is a successful strategy for producing excellent quality at a cost that is relatively cheap. Enhancing one parameter causes other parameters to deteriorate, thus it is far more difficult to optimize different parameters. The characteristic multiple performance in drilling operations is therefore investigated using the Taguchi technique. The impact of changing machining parameters, including speed, power, cutting depth, and radius nose in Al6063-T6, has been researched and discussed in this work. First, by using arrangement of the orthogonal arrays of Taguchi L_9 approach with a modification in three levels, the ideal arrangement of the four rotational parameters has been found. The numbers are recorded and compared utilizing statistical analysis software when the machining is finished.

Mohammed Hasian Y, Gopinath T S [2015] The aesthetics of the finished product are affected by the methodology of the Customized Taguchi optimization technique for simultaneous minimization and maximization of Surface roughness (Ra), machining time, and material removal rate of EN31, and it is crucial to choose the best combination values of the Numerically controlled drilling process parameters in order to minimize as well as maximize the responses. For the experiments, a CNC lathe was used to machine EN31 while employing physical vapour deposition coated & uncoated HSS drilling tool inserts.

Each experimental study was conducted under a specific set of circumstances, such as speed, drilling tool type, and feed rate, according to the L_{27} orthogonal array. To determine the relative impact of the machining parameters on Surface roughness (Ra), Machining time, and Material Removal Rate (MRR), the Taguchi technique and analysis of variance (ANOVA) were used with the MINITAB-16 programme.

Khushboo Sharma , Gaurav Kumar and Mukesh Kumar [2020] The drilling process parameters are optimized using Taguchi's technique in this article because it is a simple and organized way to do it. The results show that $A_2B_3C_1D_3$ with no cutting fluid present, speed of 420 rpm, feed of 120 mm/min, and hole depth of 24 mm is the best possible combination of many performance characteristics for drilling AA 6082. According to the ANOVA results, the feed has the greatest influence, followed by cutting fluid, speed, and hole depth. By using this approach, a 12.39 percent improvement is seen.

More optimization techniques, such as ANN models, genetic algorithms, cuckoo searches, RSM, etc., could be used for analysis in the future. There is always room for improvement.

Prashant Chavan , Sagar Jadhav [2016] In the manufacturing sectors, we can improve performance by using optimization approaches. In the very competitive market of today, businesses seek to produce goods of the best quality in the shortest amount of time. Therefore, choosing the best input cutting parameters for machining operations in order to improve product quality is a challenge for all businesses. This experimental study used the Taguchi technique of optimization to optimize a process parameter for surface roughness during drilling of spheroidal graphite 500/7 material. As cutting parameters for the experiment, the spindle speed, feed rate, and cutting tool material have been taken into consideration. We have chosen the best spindle speed, feed rate, and tool material combinations to achieve the least amount of surface roughness.

N.S. Patel [2021] In order to increase productivity and surface finish, this study looked into how drilling parameters like rotation speed and rate of feed affected the inner surface of a gear shifter produced by "Shree Chamunda Engineering Works." To identify the ideal drilling parameters, an experimental investigation using the L_9 orthogonal array of Taguchi method was carried out on a gear shifter made of “IS 10,343 Gr. 2A”. To ascertain the response's significance and the relative contribution of each parameter to the response, analysis of variance (ANOVA) was also carried out. To verify the test results, a verification test was run. The findings showed that the optimum process parameters had produced a 3.006 percent decrease in the rejection of the gear shifter.

J. Sarath Chandra [2018] The inner surface of the gear shifter, a byproduct of "Shree", was examined in this study to determine the impact of drilling's cutting parameters, such as rotation speed and feed. Shree Aluminum-matrix composites (AMCs) have replaced cast iron in the aerospace and automotive industries on a large scale in recent years. A greater grasp of cutting operations with regard to precision and efficiency is necessary for the machining of this Aluminium and EN31. The thrust force and torque in the drilling operations of hybrid composite materials were examined in this work utilizing multiple linear regression model (MRA) and genetic algorithms (GE).

Rotation speed, rate of feed, and volume fraction of the reinforcement particles are used as input data, while the thrust force and torque are used as output data, to identify the models. To evaluate the prediction accuracy of the two prediction methods, a comparison is being developed. We discover that the spindle speed is either insignificant or significant in this situation, and it instructs us to set it whether at the maximum spindle speed to achieve a high rate of material removal or at the least spindle speed to extend the tool's life, depending on the requirements of the application.

R. Deepak Joel Johnson [2014] Cutting fluids are extensively utilized in the metal cutting process to serve the two primary purposes of cooling and lubricating. Flood or deluge cooling, which involves applying cutting fluid in large quantities throughout the cutting zone, is the most popular technique for applying cutting fluid. Cutting fluid is widely used, which not only raises production costs but also poses major environmental and health risks. In the current study, an effort was made to use less cutting fluid when turning Oil Hardened Non-Shrinkable Steel (OHNS) using the Taguchi technique, as well as to optimize the cutting conditions and fluid application parameters. Under comparable cutting conditions, the optimized outcomes were contrasted with dry turning and traditional wet turning. The findings made it abundantly evident that cutting performance was improved with minimum cutting fluid application over dry and wet turning by enhancing surface finish.

Mostafa A. Abdullah [2016] The goal of the current study was to evaluate how the cutting circumstances (rotation speed, rate of feed, diameter of the tool) characteristics as input impacted the steel's surface roughness (Ra) and material removal rate (Material removal rate) (AISI 1015). Wet cutting circumstances were used in a variety of drilling trials employing the L_9 orthogonal array on a typical drilling machine with feed rate (0.038, 0.076, 0.203) mm per rev, spindle speed (132, 550, 930) rpm, and tool diameter (11, 15, 20) mm High speed steel twist drills. The most important control factors influencing surface roughness and Material removal rate were identified using analysis of variance (ANOVA). The results showed that the tool diameter had a significant impact on MRR and surface roughness, with effects of 64.08 percent and 76.12 percent, respectively.

2.2 OBJECTIVE OF PRESENT WORK

- The aim of this research is to study the surface roughness, material removal rate and tool wear while drilling Al 6063 alloy with HSS tool.
- A major intention of this work is to find out the optimal values for all the output results using different combinations of machining parameters that will give us the desired quality of hole as mentioned below :

A. Minimum roughness of the hole,
B. Minimum wear of the tool, and
C. Maximum rate of material removal.

- The impact of different drilling conditions on the quality of the drilled hole is analyzed using the signal-to-noise (S/N) ratio, orthogonal arrays of Taguchi, and analysis of variance (ANOVA) for finding out the optimal output values.
- It helps in calculating the values of process parameters which will result in the required quality of the workpiece (meet essential requirements).
- This work also helps in increasing production efficiency with the existing resources, which is a big issue encountered by engineers during the production operation.

2.3 DIFFERENT TYPES OF PROCEDURES INVOVLED IN THE PRESENT WORK PERFORMED

To accomplish the goals, this research includes the following processes:

- The influence of multiple drilling parameters on the accuracy of the drilled hole is analyzed using S/N (signal-to-noise) ratio, orthogonal arrays of Taguchi, regression analysis, and analysis of variance (ANOVA).
- CNC Milling Machine is used to perform a number of experiments with the help of L_{18} orthogonal arrays of Taguchi.
- MINITAB 19, a commercial software tool, is used to collect and evaluate the results of the experiments.
- For establishing a connection between the selected input parameters and the quality aspects of the holes made, linear regression equations are used.
- The experimental data are compared to the expected values, which are quite similar.

CHAPTER – 3

DESIGN OF EXPERIMENTS

3.1 DESIGN OF EXPERIMENT (DOE)

Design of Experiment is a useful method for enhancing design of the product or procedure performance, therefore it is applied for speeding up the development of new goods or processes. A design of experiment is a test or set of tests that examines the drilling parameters of the procedure in order to detect and identify equivalent changes in the system response. The output obtained from the procedure is examined in order to establish the ideal value or factors with the greatest influence.

3.2 TAGUCHI METHOD

When Taguchi began exploring for ways to enhance product quality, it was in the 1950s while he was designing a telephone-switching system. His theories were warmly welcomed in Japan, and in the 1980s, they received attention in the West. Well-known businesses like Ford, Toyota, and Boeing adopted Taguchi's strategies. Utilizing statistics to evaluate quality, the method computed loss.

Although using the loss function to measure quality has its critics, Taguchi designed his technique to differ from the standard. His theories present an alternative viewpoint on data processing and analysis. The Taguchi methods take into account a product's loss to society because they use the loss function. Variations in a product's performance and the side effects it produces are used to calculate loss. The result of this computation is the loss of variation in function, that indicates how far a product deviates from its intended function. Among the fields that make use of Taguchi's methodology are marketing, biotechnology, and advertising.

The Taguchi technique is a statistical approach for estimating the response independently with the minimum number of trials. The Taguchi method can also be used to improve product quality, It is a proven method for generating high-quality industry goods. The Taguchi technique is a powerful tool for creating processes that perform reliably and ideally across a wide range of circumstances. The utilization of carefully designed tests is required to establish the best design. Taguchi proposed a novel concept called as Orthogonal Array, which aims to minimize the number of trials by taking specific control characteristics into consideration. The orthogonal array allows for the least number of testing. The variation from a design experiment was measured using the Taguchi method's S/N (signal-to-noise) ratio. When the mean (signal) is divided by the standard deviation (noise) then the value obtained is known as the S/N ratio. The procedure for determining the S/N ratio varies with each experiment performed. Three characteristics values are then converted into S/N (signal-to-noise) ratio using Taguchi technique. According to the problem's objective, these three values indicate various quality characteristics. "Larger is better", "Smaller is better", and "Nominal is the best" are the characteristic values of the S/N ratio. S/N ratio is estimated for every level of input parameters based on S/N analysis, with smaller being preferable. The quality characteristic employed in this study is “smaller is better” for surface roughness and tool wear but in case of material removal rate “Larger is better” is used.

Case 1: S/N ratio larger is better

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

Case 2: S/N ratio smaller is better

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

Case 3: S/N ratio nominal is best

$$SN_t = 10\log\left(\frac{\bar{y}^2}{s^2}\right)$$

Figure 2.1: Characteristic values for calculating s/n ratios

3.3 USE OF S/N RATIO

The strength of the signal is compared to the strength of the noise in a signal-to-noise ratio. Decibels are the most typical unit of measurement for it (dB). Higher numbers often denote a better specification (the noise) because there is more important information (the signal) than undesired data.

For example, a 100 dB signal-to-noise ratio means that its audio signal level is 100 dB higher than that of the noise level. Consequently, a specification with a value of 100 dB or above is more preferred over one with a value of 70 dB or below.

Let's use an example where you're talking to a friend in their kitchen, which also happens to have a really noising refrigerator. As the refrigerator maintains the temperature of its contents, let's also assume that it makes a 50 dB hum. The refrigerator's hum drowns out your friend's speech, so if he or she is whispering at 30 dB (consider this the signal), you would not be able to hear a word they say. Even at 60 dB, you might have to ask your acquaintance to repeat themselves, so you can ask them to speak louder. At least your words will be heard and understood when you speak at 90 dB, which may sound more like a yelling battle. The signal-to-noise ratio is based on this principle.

In Taguchi designs, a robustness metric is utilized to discover control elements that minimize the impact of uncontrollable factors to lower variability in a product or process (noise factors). Controllable design and process parameters are referred to as control factors. Noise issues can be managed during experimentation but not during product use or manufacture. In a Taguchi-designed experiment, you modify noise variables to introduce variability; from the findings, To make the whole process or product resilient, or resistant to change from the noise factors, you can decide what the ideal settings for the control elements should be. A higher signal-to-noise ratio (S/N) number indicates that the noise factors are being controlled in a way that reduces their impact. Taguchi experiments often employ a two-step optimization strategy:

Step 1- Use the signal-to-noise ratio to locate the variables under control that lower variability. **In step 2**- To find the control variables that shift the mean toward the desired value while having little to no impact on the signal-to-noise ratio.

How the answer varies in relation to the nominal or target value under various noise situations is measured by the signal-to-noise ratio. Depending on the objective of the experiment, we can select from a variety of signal-to-noise ratios.

3.4 REGRESSION ANALYSIS

A series of statistical procedures utilized during mathematical modelling for evaluating the linkage among the dependent variables and one or more than one independent variables is called as Regression analysis. The very basic type of regression model is linear type model, in which we get a line (or, a more advanced linear combination) that perfectly represent the data according to a set of mathematical conditions. For prediction and forecasting, it is commonly used.

Linear regression equations obtained from the above data for finding out the relationship among the specified input parameters for drilling circumstances on Al 6063. For multiple input parameters, linear type models have been generated by commercial Minitab 19 software and are presented here:

Surface Roughness (Ra) = $1.603 - 0.0300X - 0.000157Y + 0.806Z$

Material removal rate = -1654 + 255.4X + 1.8306Y + 3239Z

Tool Wear = -1.215 + 0.0731X + 0.000636Y + 6.600Z

3.5 ANALYSIS OF VARIANCE (ANOVA)

The Analysis of variance (or, ANOVA) is a strong and widely used statistical analysis tool that is based on the law of total variance. It's a programme that determines the impact of specific elements. ANOVA is a set of statistical concepts and methods used in statistics where the observed variance is divided into sections because of several independent variables. In the simplest form or sentence, Analysis of variance is a statistical analysis tool that determines if the means of several groups are just the same, and hence generalizes.

Role of ANOVA:

ANOVA examines the means of various groups and identifies any statistically significant variations between the means, just like other forms of statistical tests. An omnibus test statistic, ANOVA falls under this category. This implies that it can only say that at least two of the groups were statistically distinct from one another, not which individual groups were. It's crucial to keep in mind that the fundamental research question for an ANOVA is whether the sample means come from various populations. It is predicated on the following two propositions:

1. The observations within each sampled population are normally distributed, regardless of the method of data collection.
2. A common variance is present in the sampled population.

3.6 EXPERIMENTAL DATA

Table 3.1: The values of input variables

Values	Input variables		
	Tool diameter (mm) (X)	**Rotation speed (rev per min) (Y)**	**Feed rate (mm per rev) (Z)**
1	6	600	0.10
2	8	900	0.16
3	-	1400	0.22

These values are selected only after going through a number of thesis, dissertation, projects, and research work of previous years. These combination as well as individual values had never been considered before in any drilling related research which are available online.

With these values of input variables and the application of orthogonal arrays of Taguchi in the Minitab statistical software, we can find the different combinations of input variables using L_{18} orthogonal array which can be seen in the following table:

Table 3.2: L_{18} Orthogonal Array of Taguchi

Serial number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool diameter (mm)
1	600	0.10	6
2	600	0.16	6
3	600	0.22	6
4	900	0.10	6
5	900	0.16	6
6	900	0.22	6
7	1400	0.10	6
8	1400	0.16	6
9	1400	0.22	6
10	600	0.10	8
11	600	0.16	8
12	600	0.22	8
13	900	0.10	8
14	900	0.16	8
15	900	0.22	8
16	1400	0.10	8
17	1400	0.16	8
18	1400	0.22	8

CHAPTER – 4

EXPERIMENTAL WORK

4.1 EXPERIMENTAL SETUP

In the present work, the machining processes are performed on a CNC Milling machine present in the workshop of our Integral University, Lucknow. Al 6063 alloy is selected for the current study. Specifications of the machine can be seen in the table below. After Lathe machine, second most used machine in the workshop is Milling machine, here we performed the drilling operation with the help of commands controlled by Sinumerik 828D siemens CNC system controller. The rotary drill tool rotates at specified velocity and material is removed from the workpiece in the form of chips of different shapes and sizes. Figures of the CNC Milling Machine can be seen in the next page.

Table 4.1: Technical specifications of CNC Milling machine

Model	X 6323
Table dimension Width, Length	230, 1070 mm
Travel x, y, z – axis	610, 350, 380 mm
Head structure	Phased gear head (PGH)
	Vertical steel head (VSH)
	Non-phased head (NPH)
Spindle speed	PGH : 80 – 5400 rpm
	VSH : 80 – 8400 rpm
	NPH : 60 – 4200 rpm
Spindle feed rate	0.038, 0.076, 0.203 mm/rev.
Spindle rotation angle	45°
Motor output	3HP
Ram travel	305 mm
Ram rotation angle	360°
Machine size (L × W × H)	1500 mm × 1530 mm × 2100 mm
Machine load	250 kg

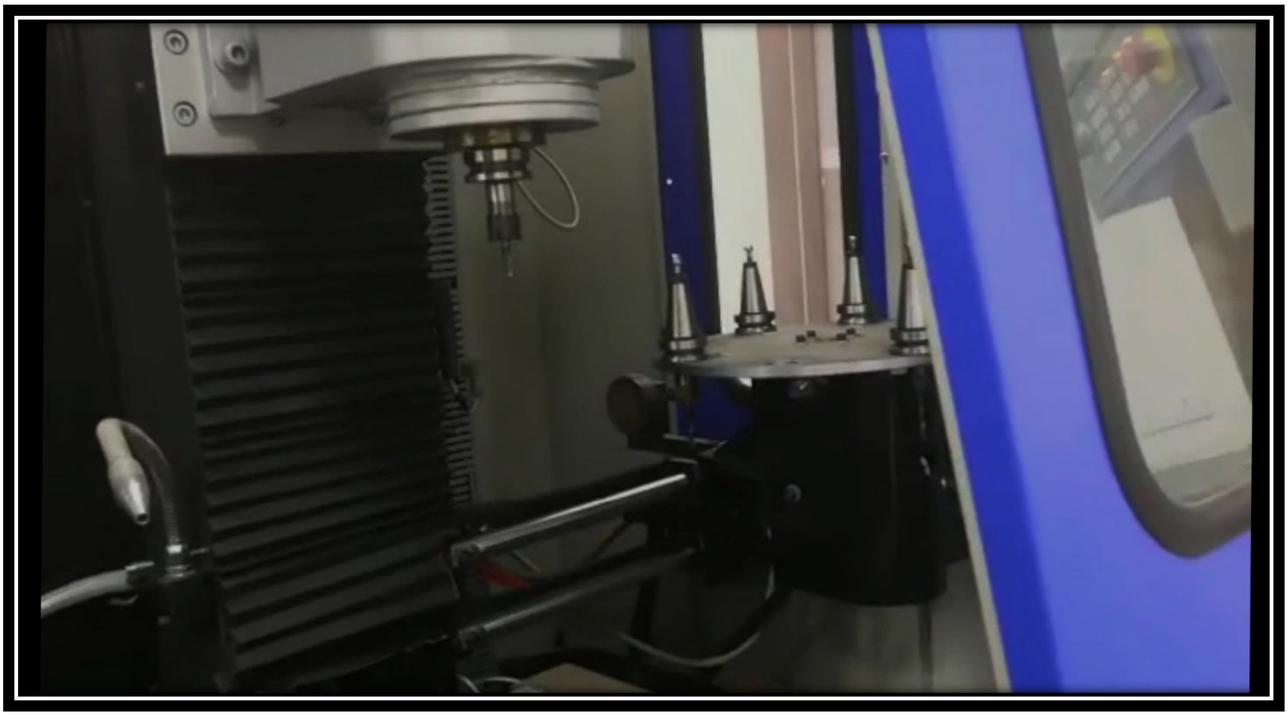

Figure 4.1: CNC Milling machine

Figure 4.2: Sinumerik 828D siemens CNC system controller

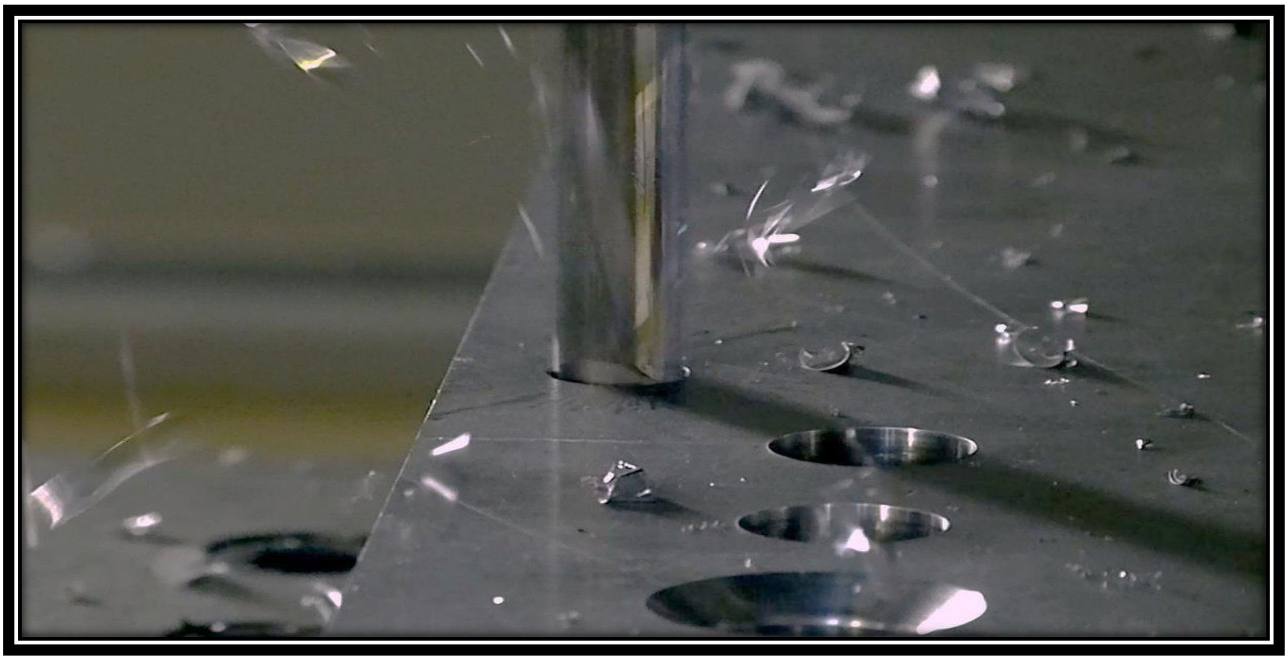

Figure 4.3: Performing drilling operation on Al 6063 plate

4.2 MATERIAL OF THE WORKPIECE

For the current experiment, the workpiece used is Aluminium 6063 with the following specifications.

Work material specification -

Work material - Al 6063

Work material dimension - $250 \times 20 \times 10$ mm^3

Table 4.2: Properties of Aluminium 6063

Properties	Magnitude
Density	2.7 gm/cc
Melting point	600ºC
Poisson's ratio	0.3
Modulus of elasticity	70 GPa
Tensile strength	195 MPa
Shear strength	150 MPa
Proof stress	160 MPa at 0.2%

Table 4.3: Aluminum alloy's chemical components in percentage

Al 6063 alloy	Weight %
Magnesium (Mg)	0.45 - 0.9
Silicon (Si)	0.2 - 0.6
Iron (Fe)	0.35 (Max)
Copper (Cu)	0.10
Zinc (Zn)	0.10 (Max)
Titanium (Ti)	0.10 (Max)
Manganese (Mn)	0.10 (Max)
Chromium (Cr)	0.10
Others	0.05
Aluminium (Al)	Remaining

Figure 4.4: Workpiece plate before machining

Figure 4.5: Workpiece plate after machining

4.3 APPLICATIONS OF ALUMINIUM 6063

Due to its outstanding workability, weldability, and moderate strength, Aluminium 6063 is frequently utilized in extrusion applications. These characteristics make Aluminium 6063 ideal for architectural applications; as a result, it is frequently utilized in these settings and is sometimes referred to as "architectural Aluminium". The examples below therefore employ Aluminium 6063 alloy, but keep in mind that this is by no means an exhaustive list:

- In Pipes,
- In Tubes,
- General extrusion for medical, automotive, parts profiling and more,
- In Architectural industry,
- Building and construction extrusion,
- Recreational instrument,
- Furniture.

4.4 TOOL MATERIAL

High Speed Steel drill bits of 6 mm and 8 mm are used for the present work. Because it can tolerate intense heat without losing the properties (hardness), it is preferable to the earlier high-carbon steel tools which were widely used throughout the 1940s. High-speed steel (HSS) is so named due to its ability to cut more quickly than high carbon steel.

4.5 MEASUREMENTS

The main focus of the dissertation is to calculate the optimal combinations of the “Surface roughness”, “Tool wear”, and “Material removal rate” of Aluminium 6063 while drilling is performed and the impact of “Spindle speed”, “Feed rate”, and “Drill tool diameter” are to be evaluated.

4.5.1 SURFACE ROUGHNESS

The Surftest SJ-201P (Compact surface roughness testing machine) is a popular tool for determining component’s shape and form. A tactile measurement principle is commonly used in profile measurement devices. On moving a stylus across the surface measures roughness, A transducer translates the movements of the stylus as it moves up and down along the surface into pulse, which is subsequently converted into a roughness value, which can be seen in a visible screen. A surface representation is often formed by combining many profiles. Figure 4.6 shows the Surftest SJ-201P. Testing has been conducted in Spectro Research lab ventures ltd. Situated in Kanpur (UP).

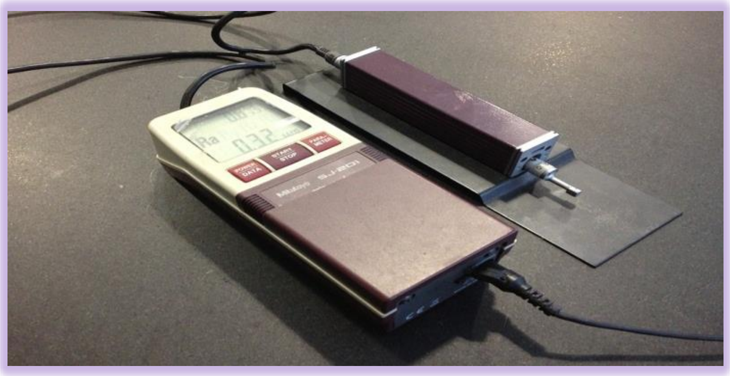

Figure 4.6: Surftest SJ 201 P

4.5.2 MATERIAL REMOVAL RATE

The amount of material removed per unit of time during machining processes including milling, turning, drilling, and grooving is known as the material removal rate (MRR). In cubic inches per minute or cubic centimeters per minute, it is denoted by the letter ‘Q’. In this work, Material removal rate is calculated with the use of the formula as discussed below:

Material removal rate (Q) = ($\prod$* D^2 * f * N) / 4

Where, 'D' is the drill tool diameter in mm.

'f ' is the rate of feed in mm per revolution.

And 'N' is the rotation speed in RPM.

4.5.3 TOOL WEAR

Tool wear is the slow deterioration of cutting instruments resulting from routine use. Affected tools include drill bits, tool bits, and pointed tools used with machine tools.

Few basic results of tool wear are as follows:

- Increase in force of cutting.
- Increase in the temperature of cutting.
- Low surface quality.
- Less accurate finished product.
- Tool can break anytime.
- Geometry of the tool changes.

Tool wear is measured by weighing the drill bits before and after each drilling process performed with the help of **"Digital electronic balance"** available in the Integral University, Lucknow.

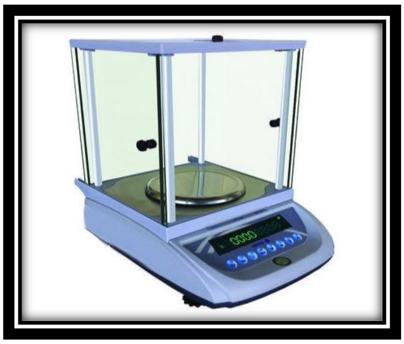

Figure 4.7: Digital electronic balance

4.6 MACHINING PARAMETERS

Geometry and machining parameters influence the drilling process. Three major modifiable machining factors in a straightforward drilling operation are the focus of this investigation viz. “Spindle speed” in revolution per minute, “Feed rate” in mm per revolution, and “Drill tool diameter” in mm. Additional input variables affecting the quality characteristics such as surface roughness, material removal rate and tool wear are kept constant throughout the machining process.

Spindle speed:

The machine's spindle's rotating frequency, expressed in revolutions per minute, is known as the spindle speed (RPM). The preferred speed (of workpiece or cutter) can be obtained by working backwards from the desired surface speed (m/min) and accounting for the diameter. Premature tool wear, breakages, and clatter can all result from excessive spindle speed, which can create potentially hazardous circumstances. Tool life and surface finish quality will be considerably improved by using the proper spindle speed for the material and tools.

The cutting speed will typically remain constant for a given machining operation, which means that the spindle speed will likewise remain constant. For this study, the spindle speeds are taken as 600, 900, and 1400 RPM.

Feed rate:

One of the cutting factors is feed rate, which is used to move the tool against the workpiece and cover the full surface that needs to be machined. Although it is typically transmitted in a direction perpendicular to cutting velocity, the angle between the feed vector and cutting velocity vector may diverge from 90 degree. The feed direction, along with speed and depth of cut, are shown in the following schematic picture for a straight turning operation. In this study the feed rate is taken as 0.10, 0.16, and 0.22 mm per revolution.

Before the machining, choosing the best feed rate is essential since the process parameter affects a variety of variables. An optimization can assist in determining the best feed rate range for machining a specific material under various circumstances and cutting environments. It can be challenging to take into account every potential factor, hence in machine shops, the value is frequently chosen based on actual experience.

Drill tool diameter:

The cutting instruments used by drilling machines are called drill bits. They can be built to order in any size, but standards groups have established sets of sizes that drill bit manufacturers regularly produce. In this work, drill tool diameter taken for the experimentation are 6 mm and 8 mm respectively.

CHAPTER – 5

RESULTS AND DISCUSSION

5.1 CALCULATION FOR SURFACE ROUGHNESS, TOOL WEAR AND MATERIAL REMOVAL RATE

The surface roughness which produces during the drilling process inside the hole, that is measured with the help of "**Surftest SJ 201P"**. And the value obtained after the testing is noted down in micrometres. Which is denoted by "**µm"**

While Tool wear is calculated by weighing the tool before and after each drilling process and the measured values are noted down in "**grams**". For this, we used "**Digital electronic balance machine"**.

And the last output parameter, Material removal rate is calculated with the use of the **formula** as discussed earlier and the values are noted down in "**mm^3 per minute**".

5.2 CALCULATION OF S/N RATIOS FOR SURFACE ROUGHNESS, TOOL WEAR AND MATERIAL REMOVAL RATE

For calculation of s/n ratios for surface roughness and tool wear "smaller is better" quality characteristics is used.

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$$

But in case of material removal rate "Larger is better" is used.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]$$

5.2.1 CALCULATION FOR SURFACE ROUGHNESS

Table 5.1: Experimental results of Surface roughness

Serial number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool diameter (mm)	Roughness (Ra) (µm)
1	1	1	1	1.43
2	1	2	1	1.46
3	1	3	1	1.49
4	2	1	1	1.42
5	2	2	1	1.50
6	2	3	1	1.52
7	3	1	1	1.25
8	3	2	1	1.24
9	3	3	1	1.29
10	1	1	2	1.26
11	1	2	2	1.30
12	1	3	2	1.34
13	2	1	2	1.33
14	2	2	2	1.47
15	2	3	2	1.50
16	3	1	2	1.22
17	3	2	2	1.29
18	3	3	2	1.35

After using L_{18} orthogonal arrays of Taguchi, we provide the testing results of surface roughness in the Minitab-19 software which gives us the values of s/n ratios for each input as shown in the table below:

Table 5.2: S/N ratios for Surface roughness of Al 6063

Serial Number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool Diameter (mm)	S/N response values for Roughness (Ra) in decibel
1	1	1	1	-3.10672
2	1	2	1	-3.28706
3	1	3	1	-3.46373
4	2	1	1	-3.04577
5	2	2	1	-3.52183
6	2	3	1	-3.63687
7	3	1	1	-1.93820
8	3	2	1	-1.86843
9	3	3	1	-2.21179
10	1	1	2	-2.00741
11	1	2	2	-2.27887
12	1	3	2	-2.54210
13	2	1	2	-2.47703
14	2	2	2	-3.34635
15	2	3	2	-3.52183
16	3	1	2	-1.72720
17	3	2	2	-2.21179
18	3	3	2	-2.60668

Calculation of mean s/n ratio for surface roughness:

The values of mean s/n ratio are also obtained from the Minitab software which is shown in the next page.

The factors which impact the machining parameters shown in the table with their respective ranks. Ranks of the parameters are dependent on delta values. The 'first rank indicates that the delta value of one parameter is greater than the others. Higher value of s/n ratios of every factor gives the optimal level values. The most effective machining parameter for Surface roughness is the Spindle speed followed by the Feed rate and Tool diameter.

Table 5.3: Mean S/N ratio for Surface roughness

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	-2.898	-2.781	-2.384
2	-2.524	-3.258	-2.752
3		-2.094	-2.997
Delta	0.373	1.164	0.613
Rank	3	1	2

Analysis of variance for surface roughness:

Table 5.4: ANOVA Result of Surface roughness

Source	DF	Sum of square (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage (%)
X	1	0.6276	0.6276	5.34	0.039	8.61 %
Y	2	4.1105	2.0552	17.49	0.000	56.36 %
Z	2	1.1443	0.5721	4.87	0.028	15.69 %
Residual Error	12	1.4098	0.1175			19.33 %
Total	17	7.2922				100%

The ANOVA table displays the distribution of the sum of squares as per the source of variation. The term “Residual error” means the extent to which an observed variate deviates from its model-predicted value.

The residual error percentage for Surface roughness from ANOVA result is 19.33% as shown in the table above.

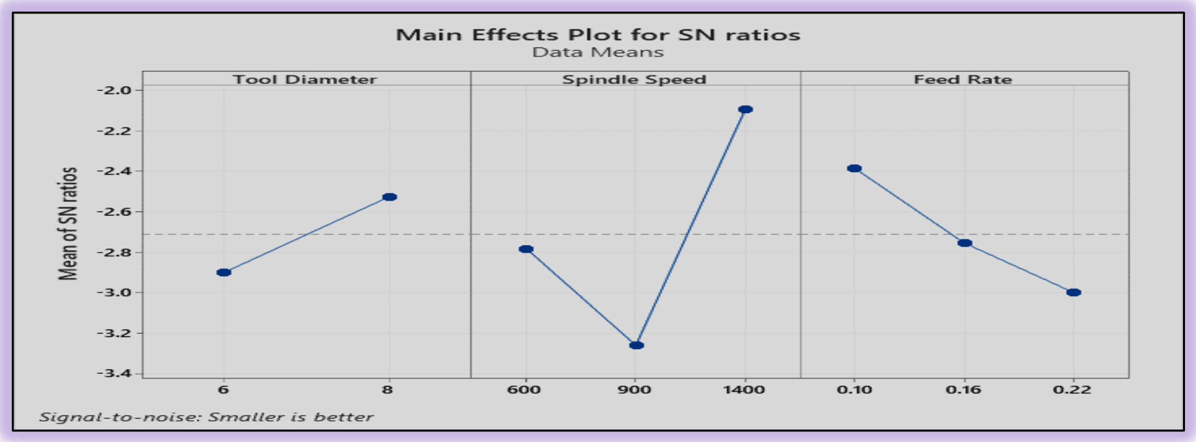

Figure 5.1: Graph for surface roughness's main effect

From the graph shown above it can be seen clearly that as we increase the diameter of the tool, the Surface roughness increases slightly. In case of spindle speed, it is clear that the Surface roughness tends to decrease initially when it varies from 600 rpm to 900 rpm but when the spindle speed is increased further to 1400 rpm, then it starts increasing. The reason for increased Surface roughness at higher spindle speed is that the thermal gradients and drill tool speed makes the drilled hole larger than the required size. It is the most significant factor influencing the Surface roughness of the drilled hole. While feed rate is the second most effective machining parameter that influence the surface roughness. From the above graph, we can see that the Surface roughness showing increasing trend with the increase in feed rate of the tool. As we increase the feed rate, the chips thickness increases which increases the roughness of the surface and hence larger sized holes are obtained.

Optimal combination of the input parameters for minimum surface roughness of the drilled hole is found at the tool diameter of 8 mm, spindle speed of 1400 rpm and feed rate of 0.10 mm per revolution.

Table 5.5: Validation of testing results for Surface roughness

	Optimal input variables	
	Estimated values	**Experimented values**
Level	$X_2Y_3Z_1$	$X_2Y_3Z_1$
Roughness	1.1916	1.22
S/N ratio of Roughness	-1.5799	-1.7272

From the above table, we can say that the result we got after the experimental process and the predicted values are quite similar for Surface roughness and this validates the results we got from the experiment.

5.2.2 CALCULATION FOR MATERIAL REMOVAL RATE

Table 5.6: Experimental results of Material removal rate

Serial number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool diameter (mm)	MRR (mm^3/min)
1	1	1	1	1235
2	1	2	1	1424.7
3	1	3	1	1556.2
4	2	1	1	1865.9
5	2	2	1	2078
6	2	3	1	2228
7	3	1	1	2864.4
8	3	2	1	3007.8
9	3	3	1	3231.5
10	1	1	2	1857.1
11	1	2	2	2026.3
12	1	3	2	2239.9
13	2	1	2	2455.7
14	2	2	2	2603.4
15	2	3	2	2819.2
16	3	1	2	3076.4
17	3	2	2	3398
18	3	3	2	3612

Similarly, as we processed for Surface roughness, we used L_{18} orthogonal arrays of Taguchi and provided the calculated values of Material removal rate in the Minitab-19 software which gives us the values of s/n ratios for each input as shown in the table below:

Table 5.7: S/N ratios for Material removal rate of Al 6063

Serial Number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool Diameter (mm)	S/N response values for MRR (mm^3/min) in decibel
1	1	1	1	61.8333
2	1	2	1	63.0745
3	1	3	1	63.8413
4	2	1	1	65.4178
5	2	2	1	66.3529
6	2	3	1	66.9583
7	3	1	1	69.1407
8	3	2	1	69.5650
9	3	3	1	70.1881
10	1	1	2	65.3767
11	1	2	2	66.1341
12	1	3	2	67.0046
13	2	1	2	67.8035
14	2	2	2	68.3108
15	2	3	2	69.0025
16	3	1	2	69.7609
17	3	2	2	70.6245
18	3	3	2	71.1550

Calculation of mean s/n ratio for material removal rate:

The values of mean s/n ratio are also obtained from the Minitab software which is shown in the next page.

The most effective machining parameter for Material removal rate is the Spindle speed followed by the Tool diameter and Feed rate.

Table 5.8: Mean S/N ratio for Material removal rate

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	66.26	64.54	66.56
2	68.35	67.31	67.34
3		70.07	68.02
Delta	2.09	1.164	1.47
Rank	2	1	3

Analysis of variance for material removal rate:

Table 5.9: ANOVA Result of Material removal rate

Source	DF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage(%)
X	1	19.637	19.637	51.30	0.000	16.04 %
Y	2	91.685	45.842	119.76	0.000	74.90 %
Z	2	6.490	3.245	8.48	0.005	5.30 %
Residual Error	12	4.593	0.3828			3.75 %
Total	17	122.405				100%

The residual error percentage for Material removal rate from ANOVA result is 3.75% as shown in the table above.

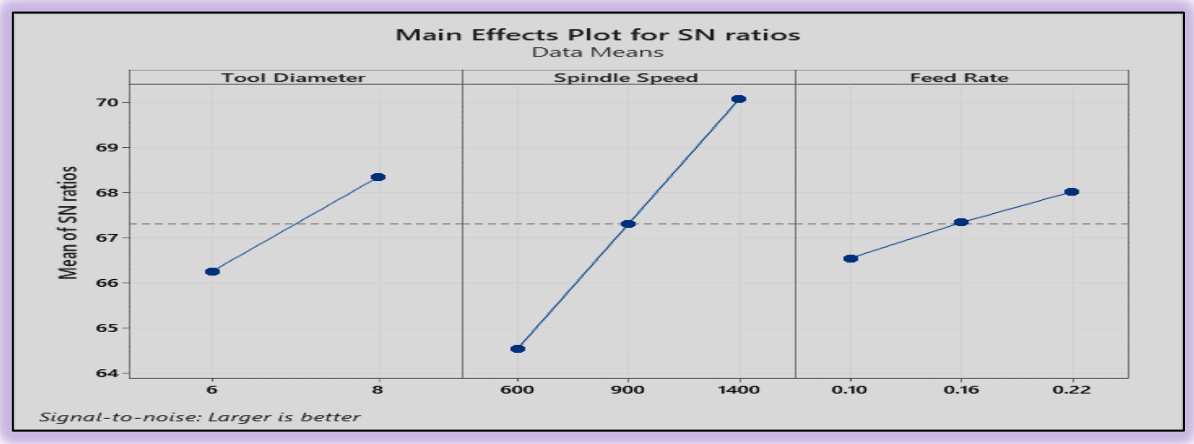

Figure 5.2: Graph for Material removal rate's main effect

From the graph shown above it can be seen clearly that as we increase the diameter of the tool, the Material removal rate increases slightly. Drill tool diameter is the second most effective machining parameter that influence the Material removal rate. In case of spindle speed, it is clear that the Material removal rate tends to increase when it varies from 600 rpm to 1400 rpm. The reason for increased Material removal rate at higher spindle speed is that the tool starts moving rapidly and due to the rapid action of the tool, material removal in the form of chips starts flowing at higher speed. It is the most significant factor influencing the material removal rate of the drilled hole during machining. While feed rate is the least effective machining parameter that influence the Material removal rate. From the above graph, we can see that the Material removal rate showing slightly increasing trend with the increase in feed rate of the tool. As we increase the feed rate, the chips thickness increases which increases the rate of material removal and hence larger sized holes are obtained.

Optimal combination of the input parameters for maximum material removal rate of the drilled hole is found at the tool diameter of 6 mm, spindle speed of 600 rpm and feed rate of 0.10 mm per revolution.

Table 5.10: Validation of testing results for Material removal rate

	Optimal input variables	
	Estimated values	**Experimented values**
Level	$X_1Y_1Z_1$	$X_1Y_1Z_1$
MRR	1272.51	1235
S/N ratio for Material Removal rate	62.7471	61.83

From the above table, we can say that the result we got after the experimental process and the predicted values are quite similar for Material removal rate and this validates the results we got from the experiment.

5.2.3 CALCULATION FOR TOOL WEAR

Table 5.11: Experimental results of Tool wear

Serial number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool diameter (mm)	Tool Wear (gm)
1	1	1	1	0.235
2	1	2	1	0.762
3	1	3	1	1.011
4	2	1	1	0.493
5	2	2	1	0.922
6	2	3	1	1.267
7	3	1	1	0.715
8	3	2	1	1.189
9	3	3	1	1.458
10	1	1	2	0.288
11	1	2	2	0.797
12	1	3	2	1.158
13	2	1	2	0.612
14	2	2	2	1.095
15	2	3	2	1.414
16	3	1	2	0.936
17	3	2	2	1.345
18	3	3	2	1.723

Similarly, as we proceed for both Surface roughness and Material removal rate, we used L_{18} orthogonal arrays of Taguchi and provided the measured values of Tool wear in the Minitab-19 statistical software which gives us the values of s/n ratios for each input as shown in the table below:

Table 5.12: S/N ratios for Tool wear

Serial Number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool Diameter (mm)	S/N response value for Tool Wear (gm) in decibel
1	1	1	1	12.5786
2	1	2	1	2.3609
3	1	3	1	-0.0950
4	2	1	1	6.1431
5	2	2	1	0.7054
6	2	3	1	-2.0555
7	3	1	1	2.9139
8	3	2	1	-1.5036
9	3	3	1	-3.2752
10	1	1	2	10.8122
11	1	2	2	1.9708
12	1	3	2	-1.2742
13	2	1	2	4.2650
14	2	2	2	-0.7883
15	2	3	2	-3.0090
16	3	1	2	0.5745
17	3	2	2	-2.5744
18	3	3	2	-4.7257

Calculation of mean s/n ratio for tool wear:

The values of mean s/n ratio are also obtained from the Minitab software which is shown in the next page.

The most effective machining parameter for Tool wear is the Feed rate followed by the Spindle speed and Tool diameter.

Table 5.13: Mean S/N ratio for Tool wear

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	1.975	4.392	6.214
2	0.583	0.876	0.028
3		-1.432	-2.406
Delta	1.391	5.824	8.620
Rank	3	2	1

Analysis of variance for tool wear:

Table 5.14: ANOVA Result of Tool wear

Source	DF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage(%)
X	1	8.711	8.711	3.61	0.082	2.3 %
Y	2	103.213	51.607	21.40	0.000	27.31 %
Z	2	237.005	118.502	49.15	0.000	62.72 %
Residual Error	12	28.932	2.411			7.65 %
Total	17	377.860				100%

The residual error percentage for Tool wear from ANOVA result is 7.65% as shown in the table above.

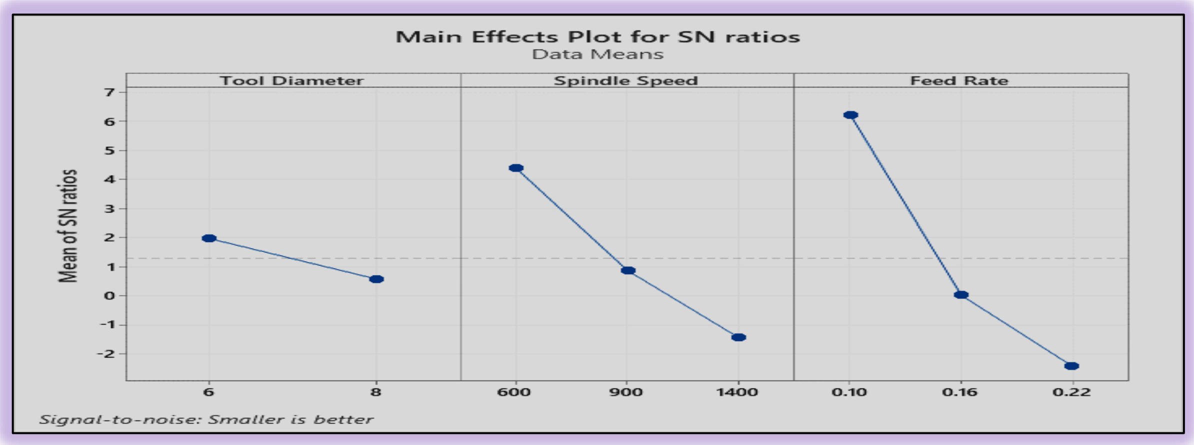

Figure 5.3: Graph for Tool wear's main effect

From the graph shown above it can be seen clearly that as we increase the diameter of the tool, the Tool wear decreases slightly. Drill tool diameter is the least effective machining parameter that influence the Tool wear. But, in case of spindle speed, it is clear that the Tool wear tends to decrease when it varies from 600 rpm 900 rpm and 900 rpm to 1400 rpm again. The reason for decreased Tool wear at higher spindle speed is that the tool starts moving rapidly and due to the rapid action of the tool, material removal in the form of chips starts flowing at higher speed and drilling process takes less time to complete. It is the second most significant factor influencing the Tool wear of the HSS tool during machining. While feed rate is the most effective machining parameter that influence the Tool wear. From the above graph, we can see that the Tool wear showing decreasing trend with the increase in feed rate of the tool. As we increase the feed rate, the rate of material removal from the workpiece increases and hence the drilling process takes less time to make a hole.

Optimal combination of the input parameters for maximum material removal rate of the drilled hole is found at the tool diameter of 6 mm, spindle speed of 600 rpm and feed rate of 0.10 mm per revolution.

Table 5.15: Validation of testing results for Tool wear

	Optimal input variables	
	Estimated values	**Experimented values**
Level	$X_1Y_1Z_1$	$X_1Y_1Z_1$
Tool Wear	0.2141	0.235
S/N ratio for Tool Wear	12.578	10.023

From the above table, we can say that the result we got after the experimental process and the predicted values are quite similar for Surface roughness and this validates the results we got from the experiment.

CHAPTER – 6

CONCLUSION

CONCLUSION

In this project, Wear of the tool, Material removal rate from workpiece and Surface roughness of the sample at the entries and exits of the work material are measured using the rate of feeding, the rotation speed of the tool, and the diameter of the tool as input process parameters while drilling Aluminium 6063 alloy with High-speed-steel spiral tool. Drilling conditions are adjusted with respect to a variety of performances in order to achieve better quality of the hole while the process of drilling of Aluminium 6063 alloy. The Taguchi technique (Design of experiment) was employed to optimize the drilling settings. A tool diameter of 8 mm, rotation speed of 1400 revolution per min, and a feed rate of 0.10 mm per revolution were found to be the optimal combination of drilling conditions for producing a high value of signal to noise ratios for the surface roughness of the hole. While A tool diameter of 6 mm, rotation speed of 600 rev per min, and a feed rate of 0.10 mm per revolution were found to be the optimal combination of drilling conditions for producing high value signal to noise ratios for Material removal rate as well as for Tool wear too.

Spindle speed is the most significant factor influencing the Surface roughness of the drilled hole. The reason for increased Surface roughness at higher spindle speed is that the thermal gradients and drill tool speed makes the drilled hole larger than the required size.

Like the influence on Surface roughness, Spindle speed influences the material removal rate too. The reason for increased Material removal rate at higher spindle speed is that the tool starts moving rapidly and due to the rapid action of the tool, material removal in the form of chips starts flowing at higher speed.

But, in case of Tool wear, Feed rate is the effective machining parameter that influences it the most. As we increase the feed rate, the rate of material removal from the workpiece increases and hence the drilling process takes less time to make a hole.

Several factors [including angle of the drill point, angle of helix, no. of flutes in the drill, kind of drill tool etc.] can be included in future studies to investigate that how such factors influence the quality of the sample of other types of material or alloys.

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LIST OF PUBLICATIONS

1. "**A study of the impact of multiple drilling parameters on surface roughness, material removal rate and tool wear while drilling Al 6063 applying Taguchi technique**" Md Shahrukh Khan, Dr. Shahnawaz Alam. "International Journal of Advanced Engineering Research and Science **(IJAERS)**" Vol - 9, Issue - 6, June 2022 ISSN: 2349-6495(P) | 2456-1908(O)

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APPENDIX

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A Study of the Impact of Multiple drilling parameters on Surface Roughness, Tool wear and Material Removal Rate while Drilling Al6063 applying Taguchi Technique

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***Keywords*— Drilling, Al 6063, Taguchi method, Regression analysis, ANOVA.**

***Abstract*— *The goal of this project is to see how different drilling parameters like spindle speed (600, 900, 1400 revolution per minute), feed rate (0.10, 0.16, 0.22 mm per revolution) and drill tool diameter (6, 8 mm) affect surface roughness, material removal rate and tool wear while drilling Al 6063 alloy with an HSS spiral drill using Taguchi method. The impact of different drilling settings on the accuracy of the drilled hole is analyzed using S/N (signal-to-noise) ratio, orthogonal arrays of Taguchi, regression analysis, and analysis of variance (ANOVA). CNC Lathe Machineis used to perform a number of experiments with the help of L_{18} orthogonal arrays of Taguchi. MINITAB 19, a commercial software tool, is used to collect and evaluate the results of the experiments. For establishing a correlation between the selected input parameters and the quality aspects of the holes made, linear regression equations are used. The experimental data are compared to the expected values, which are quite similar.*

I. INTRODUCTION

In today's modern industries, the primary goal of engineers is to produce items at a lower cost while maintaining excellent quality in a short period of time. In a production process, engineers are encountering two very basic practical issues. The first one is to identify the best combination of input parameters which will result in the required quality of the product (fulfill essential requirements), and the other one is to increase production efficiency with the existing resources. Although advanced material cutting technologies have been developed in industrial sectors, but traditional drilling is still among the most practiced mechanical operations in the aerospace, aircraft, and automotive industries. L_{18} orthogonal array of Taguchi is utilized to conduct the experiment. The significant drilling parameters are selected as rotation speed, rate of feeding and diameter of the drilling tool respectively. The best combination of all the input parameters is selected to reducethe values of the performance attributes which are mentioned above. For the optimization of these parameters, Taguchi optimization method is used. ANOVA is also used to identify the extremely effective input parameter(s) which lead to a good quality product. Point angle and Helix angle are kept standard as 118 degree and 30 degree respectively.

II. DRILLING

Making holes is among the most essential requirements in the industrial procedure. Drilling is the most popular and important hole-making method, comprising almost one third of all metal cutting operations. Drilling is the process of removing a volume of metal from a workpiece by using an instrument called "a drill" to cut a cylindrical hole.

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