"Effect of Drilling Parameters on Delamination Factor and Roughness of Aluminium 6061"

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by

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CERTIFICATE

This is to certify that the thesis work entitled **"Effect of Drilling Parameters on Delamination Factor and Roughness of Aluminium 6061"** submitted by ARIF TAHSEEN**, Enrollment No.** 150100130 in partial fulfillment for the award of **Master of Technology** degree in **Mechanical Engineering Department** with specialization in Production and Industrial Engineering, to Integral University, Lucknow (U.P.). He has carried out his thesis work under my supervision and guidance and to the best of my knowledge; the matter embodied in this thesis has not been submitted to any other University/Institute for award of any degree to the candidate or to anybody else.

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ABSTRACT

High speed machining is a key method to increase the productivity and reduce the cost during manufacturing. Among all the machining processes, drilling has the highest application in assembling and fabrication parts. Roughness of the surface drilled is an important parameter for productivity. The delamination is a prevalent disadvantage while drilling of materials.

Drilling is one of the basic machining process of making holes and it is essentially for manufacturing industry like Aerospace industry, watch manufacturing industry, Automobile industry, medical industries and semiconductors. Especially Drilling is necessary in industries for assembly related to mechanical fasteners.

The present experimental research on drilling studies the process parameters that are affecting the machining performance of CNC Drilling. A combined approach is used for the optimization of parameters and performance characteristics based on Taguchi method. The design of experiments is based on Taguchi's L_9 orthogonal array. The response table and response graph for each level of machining parameters are obtained from Taguchi method to select the optimal levels of machining parameters. In the present work, the machining parameters are Spindle Speed and Feed Rate, which are optimized for minimum Delamination Factor and minimum Surface Roughness during drilling of Aluminium 6061. Analysis of Variance is also used to find out variable affecting the various responses mentioned above.

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Arif Tahseen.

Place: Lucknow Arif Tahseen

Date:

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INTRODUCTION

1.1 Introduction

High speed machining is a key method to increase the productivity and reduce the cost during manufacturing. Among all the machining processes, drilling has the highest application in assembling and fabrication parts. Roughness of the surface drilled is an important parameter for productivity. The delamination is a prevalent disadvantage while drilling of materials.

Drilling is one of the basic machining process of making holes and it is essentially for manufacturing industry like Aerospace industry, watch manufacturing industry, Automobile industry, medical industries and semiconductors. Especially Drilling is necessary in industries for assembly related to mechanical fasteners.

Drilling is the process of generating circular hole in the work-piece by using a rotating cutting tool known as drill bit. Bits are attached in a tool called a drill which helps to rotate drill-bit and also gives torque and axial force to generate the cylindrical hole in work-piece material.

Conventional mechanical drilling of aluminium alloys has to face increasing physical limitation when hole diameter is decreased. Below some decisive dimension, friction exceeds the mechanical strength of the tool and machining is possible only by diamond, carbide coated tools which are having high modulus values. In this thesis, the thrust forces, delamination factor and roughness in deep hole drilling processes are optimized. The speed, feed and the depth of cut are used as process parameters to determine the optimum drilling conditions. For this purpose, Micro drilling on Alumnium 6061 bar are carried out based on DOE (Design of Experiments), and the resultant experimental data are studied using Taguchi method.

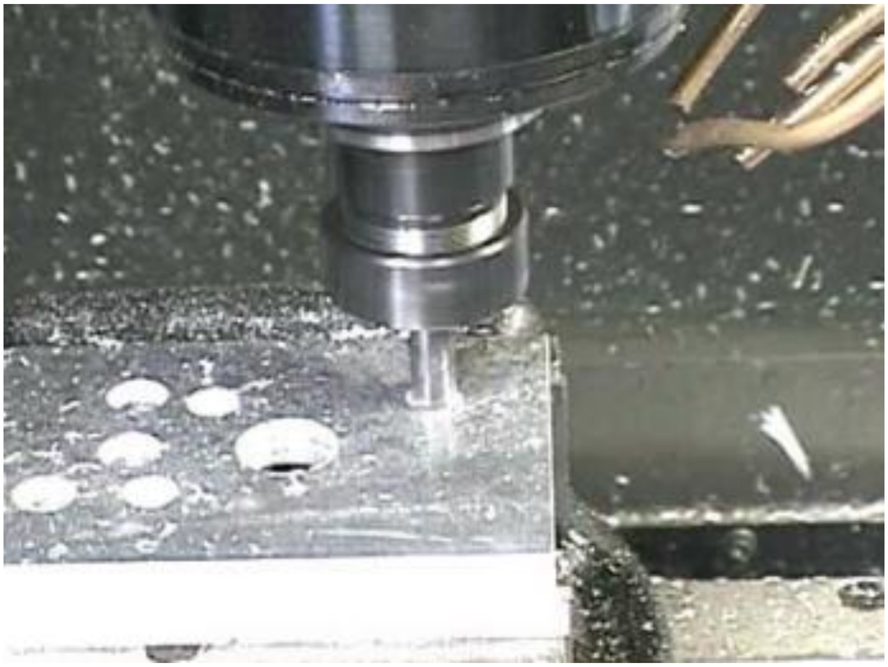

Figure 1.1 Drilling operation

1.2 Drilling Process

Drilling is the process of generating circular hole in the work-piece by using a rotating cutting tool known as drill bit. Bits are attached in a tool called a drill which helps to rotate drill-bit and also gives torque and axial force to generate the cylindrical hole in work-piece material.

1.3 Types of drills:

1. **According to Material:**

a) Steels: Generally steels are used to manufacture of drill-bit in a large number.

- Low carbon steel: Mainly used for wood material as work-piece.
- High carbon steel (HCS): These are more hardening and tempering in nature as compared to low carbon steel.

- High speed steel: This type of material is highly resistive towards heat and largely used in commercial applications.
- Cobalt steel alloy: In this type of alloy the percentage of cobalt is more in high speed steel.
- High-moly tool steel: Its heat treating temperature is at 1196° C i.e 2185° F and also has nitro-carburize finished at 510° C i.e. 950° F which stands for higher drilling temperature.

b) Other type of drill bit

- Tungsten carbide: These are extremely hard materials which can drill virtually all materials. Because of their brittleness and high cost they are usually manufactured for drill-bit tip.
- Polycrystalline diamond: This type of drill-bit is highly wear resistive and hardest in nature from all tool material. A layer of diamond granules of thickness 0.5 mm (0.019") attached as a sintered mass to above tungsten carbide.

2. Coatings

- Black oxide: This type of coating gives heat resistance, lubricity and corrosion resistance which results longer life for drill-bit than uncoated high speed steel drill-bit.
- Titanium nitride (TiN): This is a type of hard ceramic material which expands the cutting tool life by three or more times by coating on HSS drill-bit.
- Titanium aluminum nitride (TiAlN): Its extended tool life is five or more times than TiN coated drill-bit.
- Titanium carbon nitride (TiCN): This material is superior as compared to Titanium Nitride.
- Diamond powder: The diamond powder coated drill bits are mostly used for cutting tile, stone and other hard materials.
- Zirconium nitride: This type of coated drill bit usually applied in few craftsman tools.

3. Size: As per the contour of diameter, drill-bit are characterized into three types such as

(a) Micro (25-500mm),

(b) Moderate (3-25mm) and

(c) Large (25-40mm)

4. Number of flutes:

Based on the no. of flutes in drill-bit, they are named as follows

(a) Two- most common drill,

(b) Single-gun drill and

(c) Three/four slot drill

5. Helix angle: According to the measurement of helix angle, the drill bits are subdivided into four types such as

(a) Usual-20-35 degree drill,

(b) Large-45-60 degree drill,

(c) Zero degree spade drill and

(d) Micro-drill

1.4 Process Parameters

1. Cutting Speed: The cutting speed (V_c) for milling operation is defined as the peripheral speed of the cutter (tool). The cutting speed is given by following formulae

$$V_c = \frac{\pi DN}{1000}\ m/min$$

Where D is the diameter of the cutter in mm and N is the cutter speed in r.p.m.

The selection of cutting speed depends on the following factors:

a) The properties of material being cut;

b) Diameter and life of cutter;

c) Number of cutter teeth;

d) Feed;

e) Depth of cut as well as width of cut;

f) Use of coolant.

2. Feed Rate: The feed (*f*) in a milling process is defined as the movement of the work-piece relative to cutter axis. It is the rate at which the work-piece is fed into the cutter (tool).

For rough milling, the highest possible feed is employed while for finishing the feed is limited by the specified surface finish required.

Feed for milling of mild steels varies from 0.03 mm/tooth to 0.25 mm/tooth. For milling hard steels, recommended feeds are one-third to one-half of these values.

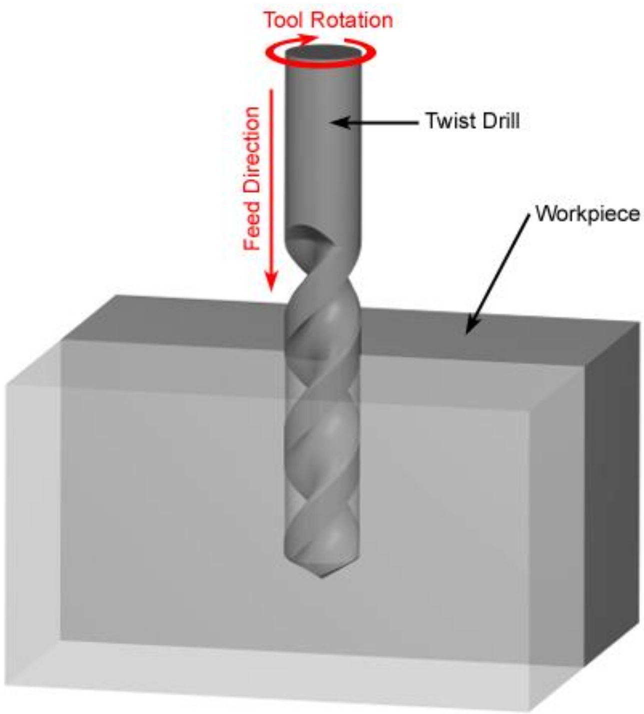

Figure 1.2: Illustration of Drilling Operation with process parameters

1.5 Advantages of Drilling Process

- All materials are compatible.
- Very good tolerances.
- Short lead times.
- High machining rate.

1.6 Disadvantages of Drilling Process

- Part may require several operations and machining.
- High equipment cost.

- Significant tool wear
- Large amount of scrap produced.

1.7 Applications of Drilling Process

Drill machine made from quality materials, using advanced technology have low maintenance and high performance with higher accuracy machining work. A variety of models provide convenience and flexibility. These machines are used in industries like manufacturing, metalworking, woodworking, masonry and construction as well. Apart from drilling holes, drill machine is featured of performing a variety of tasks like tapping, spot facing, reaming, counter sinking and counter boring etc. Tapping is a procedure to hole in pipelines under pressure. Spot facing application is furnishing finished circular surfaces around the top of a hole for seating the washer or the bolt head.

Pillar drill machine is used to drill holes in concretes, rocks, heavy duty machines, metal sheets, plastic, wood, glass and other material. It has durable bits which extends the efficiency and performance in heavy load conditions. The height and sharp assembly of the drilling machine can also be familiar.

Radial drill machine is machinery, where drilling head is mounted slip the length of a radial division which can be rotated, raised or lowered on a vertical mast to adjust the place of the drill above the work piece. The radial drill machine is much known for its precision, correctness and efficiency. Radial drills are designed for very precision and accurate work ensuring smooth rotation of column and avoid angular deflection of spindle axis. It is of very much robust construction for heavy duty drilling. Minute inspection with accuracy is required while operating radial drilling machine. The drill table is placed on a solid foundation to hold the heavy work. When the portion of work is secured on the drill table, the drill spindle may be placed over any part of the work without moving the latter.

Figure 1.3 Experimental Setup

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

J Kopac and P Krajnik [1] both have discussed about optimization process of flank milling 3 level parameters as coolant application, no of flute, cutting speed, feed per tooth, axial depth and radial depth. They optimize this experiment by grey relational analysis using L_{18} orthogonal array of design. They concluded that reducing feed rate improves the performance and the tool life.

M M Okasha and P T Mativenga [2] tested upon sequential laser mechanical drilling process on aerospace material of inconel 718 alloy. The performance of the twist drill improved by this operation and also helps in reducing burr size and increasing of tool life. They introduced Laser-Pilot-Mech technique for minimization of thrust force and torque value.

Tsai Chih-Hung et al [3] created a vendor evaluation factors model on characteristics of demand of raw materials of an enterprise by using grey theory. In this optimization method they concluded that the ranking order changes with the different value of weighs in each evaluation factor.

Goutam Nandi et al [4] modeled a optimal environment in submerged arc welding process by taking four input process parameters with five levels and they applied two hybrid method of Taguchi to optimize four bead geometrical parameters by taking L_{25} orthogonal array matrix design.

Ashish B. Chaudhari et al [5] found that noticeable reduction of entry delamination with increase of feed rate was observed. Cutting speed has less effect on entry and exit DF. After comparing the experimental results with the predicted results it is found that the root means square error (RMS) at DF at entry and exit are1.4732% and 2.9277% respectively.

Faramarz et al [6] from their research indicated that the delamination factor increased at low and high values of the parameters within the considered experimental range of the parameters. At the end, the optimum values of parameters were determined in order to minimize delamination.

Anurag et al [7] came to conclusion that the optimum delamination factor was obtained when spindle speed and feed rate are at their initial level. The optimum parameters for obtaining lower delamination factor are spindle speed and feed are in drilling a hole as 1000 rpm and 150mm/min respectively.

R. Vimal et. al [8] has Modeled and analyzed the Thrust force and Torque in drilling GFRP composites by multifaceted drill using fuzzy logic .The research has been made by taking Glass Fibre Reinforced Plastic using 8 facet solid carbide tool. 3 parameters such as spindle speed; feed rate and drill diameter with each having 3 levels using Taguchi L27 was used. Machine used was ARIX-CNC Machine centre. Thrust force and torque were taken as judging criteria for optimization of input parameters. Fuzzy rule based model was developed to indicate thrust force and torque in drilling of GFRP composites. The results suggested that the model can be effectively used for predicting the response variable by means of which delimitation can be controlled.

Yu Teng Liang et al. [9] has investigated the various Micro Machining Cutting Parameters of PMMA Polymer Material Using Taguchi’s Method and applied Grey-Taguchi method to optimize the micro-drilling of PMMA polymer with multiple performance indices. The four machining parameters were taken as coating layer, feed rate, spindle speed, and depth of cut. The performance of the drilling process was evaluated by two judging criteria, namely drill wear and surface roughness. The orthogonal array, grey relational analysis, and analysis of variance were used to study the two judging indices. The optimal combination of parameters was determined by using the grey relational grade, a performance index formed by combining the two performance characteristics.

P.F. Zhang [10] made a review on mechanical drilling process for titanium alloy which was based on micro drilling using different tools of diameter ranging from 0.05mm to 10mm with w/p material as Ti alloy. The paper presented a complete thorough review on conventional drilling processes for Titanium, namely, twist drilling, vibration assisted twist drilling, ultrasonic machining, and rotary ultrasonic machining. It discusses cutting force, cutting temperature, tool wear and tool life, hole diameter, cylindricity, surface roughness, burr and chip type as judging criteria while drilling of Ti using the mentioned processes.

Dong-Woo Kim et al. [11] reported minimization of thrust forces in the step-feed micro drilling process. An orthogonal array of L27 was used to investigate the relationship between feed rate, step-feed, and spindle rpm with that of drilling Thrust. 2mm deep hole drilling process was minimized on the work piece of size 35×35×2.3. Author had found out optimal drilling conditions based on reliable experimental results to improve the productivity in micro drilling process.

M. K.A Mohd Ariffin et al. [12] reported an investigation to optimisation of drilling cutting process which used the composite sandwich panel as testing material. 2 type of drill bit material such as HSS and carbide drill bit of diameter 3mm were selected and 4 controlling parameters such as drill bit material, cutting velocity, feed rate and hole diameter were analysed using statistical approach known as Design of Experiments. A total number of 120 holes were analyzed using Regression analysis technique to obtain the optimised range of cutting speeds. Minimum damage length was obtained for both the drill bit material for different conditions of controlling parameters.

Azlan Abdul Rahman [13] investigated the effect of feed rate, Spindle Speed, Drill bit diameter on material removal rate, Surface roughness, burr and dimensional accuracy by taking drill sizes of 0.5 to 1.0mm. Comparative analysis was done between surface roughness, MRR and accuracy of drilled holes by experimentation. Experimental result shows the increment of spindle speed and feed rate value mostly affects the tool wear and size of burr on the drilled hole edges.

Hyon-ko-Sim [14] has conducted a study on condition monitoring process on glass by using machine. The experiment was carried out on w/p material as glass of 1mm thickness and drill bit used were diamond and carbide tools with 0.3 mm dia. In the paper, a precision 3D machine vision measurement system was intended to measure hole quality and inspect drill wear in microdrilling of glass material. It was found that Positional errors of fine holes, shape of cracks, and quality of hole surfaces are influenced by drilling conditions.

Boris Stirn [15] has investigated the Burr Formation in micro drilling by using aluminum alloy and steel as W/p material with drill bit size 130μm, 250 μm and 500μm. machine parameters were diameter, cutting speed and feed rate where burr size and burr type were taken as the judging criteria. The influence of the cutting parameters on characteristic indices was observed and a comparison was being made.

W.S. Chen [16] has Investigated on the wear and performance of micro drills and presents series the influence of various factors on the efficiency of micro drilling process. He took micro drill geometry and cutting conditions as input variable along with drilling force, torque and drill wear as judging criteria. Computer controlled high speed drilling machine and piezoelectric dynamo meter (Kistler 9273) was used. The tool dia. is around 0.457mm with aspect ratio 17.5 on w/p material as printed circuit board was used for the investigation.

Arshad Noor Siddiquee et.al [17], carried out the work to study the effects of control parameters on surface roughness using drilling parameters like cutting fluid, speed, feed and hole-depth, to achieve optimal settings of output response variables like surface roughness in drilling operation of AISI 321 Stainless Steel material.

Ferit Ficici et.al [18] in this study the performance of input parameters on Surface roughness in drilling of 304 stainless steel was studied. The drilling tests were carried out to determine the roughness under various drilling conditions. Modified HSS drill with 10 mm diameter used as tool for experimental investigations. They concluded that modification of drill bit and feed were the most important factors on the surface roughness (Ra). The optimal results of the surface roughness (Ra) were obtained at lower feed rate and higher drilling speeds by using 0.5 μm drill.

Dayal Saran P et.al [19], made effort to find out effects of control factors in radial drilling. They conducted an experiment according to design matrix by using radial drilling machine. Different cutting parameters namely drill bit diameter, cutting speed, and feed rate are used for the optimal setting of the parameters on radial drilling of brass. High Speed Steel drill bits are chosen as a tool for drilling. The optimization results showed that the surface finish of the drilled hole decreases with drill speed, drill feed rate and from dry condition to wet condition. However by increasing the drill diameter surface finish value increases.

Mr. Dhanke V. D et al [20], in this study they selected AISI 1015 as a workpiece material. The purpose of this study is to optimize the input parameters for minimizing burr size by using taguchi and RSM method. Speed , feed , drill diameter and point angle was selected as input parameter and burr height and burr thickness was selected as a response variable.

Yogendra Tyagi et al [21], focused on performance of input parameters on metal removal rate and surface finish. They performed drilling operation on mild steel with the help of cnc drilling machine. Cutting speed, depth of cut and feed rate were considered as input control factor. The optimum value of machining parameters was selected to minimize surface roughness and maximize metal removal rate.

Sudesh Garg et. Al [22] were performed an experiment on CNC MILL MT250 Machining Center on AISI H11 steel. Different driing parameters like speed, feed rate and hole depth were used for the optimal setting of the parameters on drilling AISI H11 steel. The effect of drilling parameters on metal removal rate was evaluated and optimal setting conditions were determined for maximization of MRR using face centered design.

Murthy B.R et.al [23], worked is carried out on Glass Fibre Reinforced Polymer (GFRP) composite material. They selected drill diameter, spindle speed, drill point angle, feed, and material thickness, as input process parameters and thrust force and torque as output parameter. The effect of parameters such as spindle speed, drill diameter, feed rate, drill point angle and material thickness and some of their interactions were evaluated using ANOVA. They concluded that thrust force was affected by spindle speed and they are inversely proportional. Cutting torque was significantly influenced by drill diameter. cutting torque and thrust force both increase with the increase in material thickness and feed rate.

Mr.Nalawde P.S et.al [24], effort had been taken to Optimize Surface Finish and Hole Accuracy in Drilling operation. They performed experiment on EN-31 material. Speed, type of tool, feed, and depth of cut was selected as a input parameter. The effect of drilling parameters on surface finish and hole accuracy were investigated in drilling of EN-31 material with different HSS twist drill. In this work drilling operation performed using 10 mm diameter HSS TiN-coated drills, HSS TiAlN-coated drills, HSS twist uncoated drills.

Adem Cicek et.al [25], worked to find out effects of parameters on surface roughness and roundness error. In this study experiment were carried out on AISI 316 stainless steel. The effects of deep cryogenic treatment and drilling conditions were evaluated in drilling 316 stainless steel with M35 HSS twist drill as a tool.

J.Pradeep Kumar et.al [26], worked to investigate the influence of drilling parameters on tool wear, material removal rate, hole diameter error and surface roughness in drilling of OHNS material. Tool used was HSS spiral drill bit. From this study it is found that speed and feed are the most important factor that effects the output response characteristics.

2.2 Objective of present work

Above study shows that the major factors for plain turning are spindle speed and feed rate for the performance measures i.e., delamination factor and surface roughness. Thus on the basis of above study parameters spindle speed and feed are selected for this work to analyze the delamination factor and surface roughness by using drilling parameters and using Taguchi design approach

1. To find influence on Delamination Factor with spindle speed and feed.

2. To find influence on Surface Roughness with spindle speed and feed.

2.3 Different Phases of Experimentation

To accomplish the objectives, present work has been done in Two phases

Phase -I

- Development of experimental set up providing varying range of input parameters in turning and measuring the various responses on-line and off-line.
- Investigation of the working ranges and the levels of the drilling process parameters (pilot experiments) affecting the selected quality characteristics, by using one factor at a time approach.

Phase –II

- Investigation of the effects of turning process parameters on quality characteristics viz. delmaination factor and surface roughness while machining Aluminium 6061.
- Optimization of quality characteristics of machined parts:
- Prediction of optimal sets of drilling process parameters
- Prediction of optimal values of quality characteristics
- Prediction of confidence interval (95%CI)
- Experimental verification of optimized individual quality characteristics

The Taguchi's parameter design approach has been used to obtain the above objectives.

CHAPTER – 3

DESIGN OF EXPERIMENTS

3.1 Taguchi Method

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clear understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for:

- Designing products/processes so as to be robust to environmental conditions;
- Designing and developing products/processes so as to be robust to component variation;
- Minimizing variation around a target value. This philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three step approach i.e. system design, parameter design and tolerance design. In system design the engineer applies scientific engineering knowledge to produce a basic functional prototype design. In the product design stage the selection of the materials, components, tentative product parameter values etc. are involved. Since system design is an initial step, functional design may be far from optimum in terms of quality and cost.

The objective of parameter design is to optimize the setting of process parameter value for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in Taguchi method of achieving high quality without increasing cost. Basically, classical parameter design developed by Fisher is complex and not easy to use especially, a large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental values and desired values. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually there are three categorize of performance characteristic in the analysis of the S/N ratio that is the lower-the-better, the higher-the-better, and the nominal-the –better. The S/N ratio for each level of process parameter is computer based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameter is the level with the highest S/N and ANOVA analysis, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. The Taguchi method is adopted to obtain optimal machining performance in the die sinking.

1. **Larger is better (maximum) : S/NLB = -10 log ((1/n) Σ (1/y_i^2))**

2. **Smaller is better (minimum) : S/NSB = -10 log ((1/n) Σ y_i^2)**

Where, n is the number of observations or repetitions of a trial and y is the observed data. Notice that these S/N ratios are expressed on a decibel scale. We would use S/NT if the objective is to reduce variability around a specific target, S/NL if the system is optimized when the response is as large as possible, and S/N'S if the system is optimized when the response is as small as possible. Factor level that optimizes the appropriate S/N ratio is optimal.

The use of parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Analyze the experimental results using S/N ratio and ANOVA.
- Select the optimal level of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

3.2 Application of S/N Ratio

The change in the quality characteristics of a product under investigation, in response to a factor introduced in the experiment design is the signal of desired effect. However, when an experiment is conducted, there are numerous external factors not designed into the experiment which influence the outcome. These external factors are called the noise factors and their effect on the outcome of the quality characteristic under test is termed as noise. The signal to noise ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner, to those external influencing factors (noise factors) not under control. The concept of S/N ratio originated in the electrical engineering field. Taguchi effectively applied this concept to establish the optimum condition from the experiments.

The aim of any experiment is always to determine the highest possible S/N ratio for the result. A high value of S/N ratio implies that the signal is much higher than the random effect of the noise factors. Product design or process operation consistent with highest S/N ratio, always yields the optimum quality with minimum variance.

From the quality point of view , there are three possible categories of quality characteristics. They are:

1. Smaller is better;
2. Nominal I better;
3. Larger is better.

The S/N ratio is designed to measure the quality characteristics.

The Signal to Noise ratio (S/N ratio) expresses the scatter around a target value. The larger the ratio, the smaller is the scatter. Knowing the S/N ratio of the samples before and after the experiment, Taguchi's loss function may be used to estimate the potential cost saving from the improved product.

3.3 Advantage of S/N Ratio over Average

To analyze the results of experiments involving multiple runs, use of the S/N ratio over standard analysis is preferred. Analysis using the S/N ratio will offer the following main advantages:

1. It provides guidance to a selection of optimum level based on least variation around the target and also on the average value closest to the target.
2. It offers objective comparison of two sets of experimental data with respect to variation around target and the deviation of the average from the target value.

3.4 Role of ANOVA

Taguchi replaces the full factorial experiment with a lean, less expensive, faster, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is only a sample of the full experiment, the analysis of the partial experiment must include an analysis of the confidence that can be placed in the results. Fortunately, there is a standard statistical technique called Analysis of Variance (ANOVA) which is routinely used to provide a measure of confidence. The technique does not directly analyze the data, but rather determine the variability (variance) of the data. Confidence is measured from the variance.

Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is second benefit of the methodology.

3.5 Analysis of Variance (ANOVA):

This method was developed by Sir Ronald Fisher in the 1930's as a way to interpret the results from agricultural experiments. ANOVA is not a complicated method and has a lot of mathematical beauty associated with it. ANOVA is a statistically based, objective decision-making tool for detecting and differences in average performance of groups of items tested. The decision rather than using pure judgment, takes variation into account.

3.6 Tables for Taguchi Design of Experiment

Tables for Taguchi design of experiment are shown below:

Table 3.1: Process Parameters and their levels

S.No.	Parameters	Units	Level 1	Level 2	Level 3
1	Spindle Speed	RPM	1000	2000	3000
2	Feed	mm/min	150	200	250

Table 3.2: L9 Orthogonal Array

Exp No	Spindle Speed	Feed
1	1000	150
2	1000	200
3	1000	250
4	2000	150
5	2000	200
6	2000	250
7	3000	150
8	3000	200
9	3000	250

CHAPTER – 4

EXPERIMENTATION

4.1 Experimental Setup

In present investigation, the experiments are conducted on a Vertical Milling machine of model Surya VF-30 CNC VS manufactured by BFW. The material under study is Aluminium 6061. The machine specifications are shown in the table 4.1 below. Milling is the second most used machine after lathe machine, and drilling operation is performed on milling machine. The material is removed in form of chips from the work-piece by the help of rotary drill tool rotating at high velocity. The machine was available at Central Institute of Plastic Engineering and Technology, Lucknow. Figure 4.1 on the next page shows the SURYA VF 30 CNC VS milling machine.

SURYA VF30 CNC VS MILLING MACHINE	
Model	VF 30 CNC VS
Table Size (Clamping Area)	1060 mm X 315 mm
T-Slots No. / Width / Centre Distance	3 Nos. / 14 mm / 100 mm
Maximum Load on Table	300 Kg
Longitudinal Movement (X)	800 mm
Traverse Movement (Y)	350 mm
Vertical Movement (Z)	380 mm
Position Accuracy	± 0.010 mm
Repeatability	± 0.005 mm

Table 4.1: Technical Specification of Surya VF 30 CNC VS Milling Machine

Figure 4.1: Surya VF 30 CNC VS MILLING MACHINE

Figure 4.2:CNC Panel of VF 30 CNC VS Milling Machine

Figure 4.3: Setup for Machining

4.2 Work Piece Material

The material used for the present work is Aluminium 6061 with specification of 16 mm thickness.

Table 4.2 Properties of Aluminium 6061

Density g/cm³	**Melting point ºC**	**Yeild strength MPa**	**Elastic modulus Gpa**	**Possion's Ratio**	**Brinell Hardness**
2.77	617	276	68.9	0.33	95

Table 4.3 Chemical composition of Aluminium 6061 by weight

Component	Weight %
Aluminium Al	97.36%
Chromium Cr	0.21%
Copper Cu	0.15%
Iron Fe	0.5%
Magnesium Mg	0.9%
Mangenese Mn	0.15%
Silicon Si	0.4%
Titanium Ti	0.13%
Zinc Zn	0.20%

Figure 4.4: Workpiece Bars of Aluminium 6061 before machining

Figure 4.5: Workpiece Bars of Aluminium 6061 after machining

Applications of Aluminium 6061 are as follows

- Construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. Yacht construction, including small utility boats.
- Automotive parts.
- Flashlights
- Aluminum cans for the packaging of food and beverages.
- Scuba tanks and other high pressure gas storage cylinders.

4.3 Tool Material

HSS drill bit of 5 mm diameter is used as tool for the present work.

4.4 Measurements

The objective of this thesis work is to determine the delamination factor and surface roughness of Aluminium 6061 when drilling operation is performed and the influence of spindle speed (RPM) and feed (mm/min) are to be found. This thesis will quantify the influence of drilling process parameters on the damage and roughness caused on the workpiece.

4.4.1 Delamination factor

The damage zone that develops due to drilling hole was measured with the help of scanning electron microscopy (SEM). The delamination factor was determined by equation.

$$\mathbf{F_d = \frac{D_{max}}{d}}$$

Where F_d is the delamination factor, D_{max} is maximum diameter of drill damage zone and d is the diameter of drill bit. For present set of experiments, drill bit diameter is 10mm.

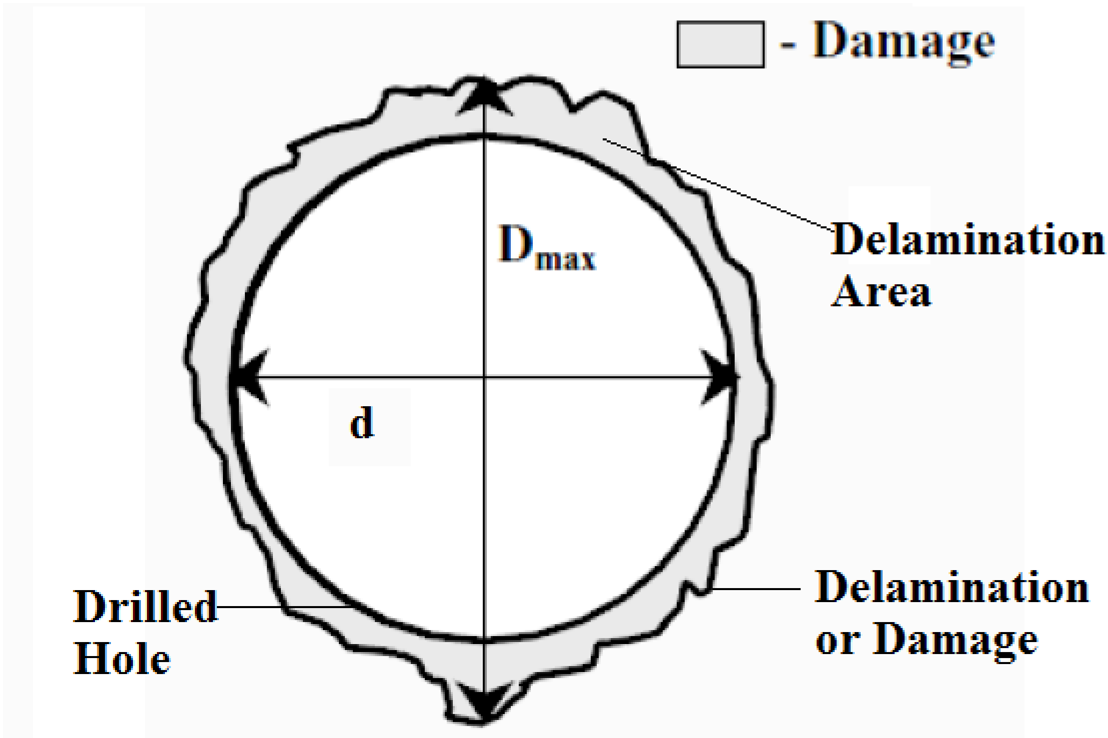

Figure 4.6 Delamination Area in a drilled hole

4.4.2 Surface Roughness

Surface roughness shows the quality of the drilling or a job. It is desirable to decrease the surface roughness of the work-piece, as much as we lower the surface roughness the surface finish of the work piece will increase and the quality of the drilling will improve. Surface roughness measurements are made using Stylus type profilometer TALYSURF surface roughness tester available at BBDNIT, Lucknow.

4.5 Machining Parameters

The drilling operation is governed by geometry factors and machining factors. This study consists of the two primary adjustable machining parameters in a basic drilling operation viz. spindle speed in RPM and feed in mm/min. Other input factors influencing the output parameters such as surface roughness and delamination factor are kept constant throughout the machining.

Spindle Speed

The drilling process consists of a series of fracture generating events. The drilling rate for a constant depth of bit indenter, penetration will depend on the bit rotational speed. The relationship between rotational speed (RPM) and rate of penetration (ROP) has been investigated by the previously mentioned authors. It has been confirmed that generally there is a near linear relationship between the two parameters in soft rocks. Drilling rate is not proportional to rotary speed in medium and hard formations due to the requirement that some finite time is required for fracture development in hard rocks. For a given penetration rate to be achieved, the bit weight and rotational speed should be continuously maintained, and adequate flush flow maintained to ensure rock cuttings removal from the hole. However, the increase in bit rotary speed result in greater wear on the bit and may also cause chatter, micro-chipping and cracking of cutting indenters or teeth of the bit. The rotational speed may also be restricted by the stability of the rig and the drill rods.

In our study the spindle or rotation speed is varied as 1000, 2000 and 3000 RPM.

Feed

It may be defined as the relatively small movement per cycle of the cutting tool, relative to the work piece in a direction which is usually perpendicular to the cutting speed direction. Feed is the distance moved by the tool tip along its path of travel for every revolution of the work piece. It is denoted as f and is expressed in mm/min. Sometimes, it is also expressed in terms of the spindle speed in mm/min as

Feed to be used depends on the following factors:

1. Smoothness of finish required
2. Power available, condition of machine and its drive
3. Type of cut
4. Tool life.

In our study the feed is varied as 150, 200 and 250 mm/min.

Drilling Fluid

The term "drilling fluid" includes all of the compositions used to remove cuttings from the borehole. An effective drilling process can only be continued, when the bottom of the hole is maintained clean. This is achieved by a sufficient flow flushing medium, which can be; air, water, oil, oil/water emulsion, mud or foam (Moore, 1958). Drilling rate is proved to be faster and bit life longer with air as compared to water or mud. Drilling was originally performed with air or water as a drilling medium used to cool the bit and flush away the drill cuttings. As these two media were usually, easily available, cheap and satisfactory for the shallow boreholes and hard formations being drilled at that time. Through the years many additional requirements have been placed on the drilling fluid. To satisfy these demands, as boreholes began to be drilled deeper, and especially with the rapid development of oil well drilling in soft and often caving sedimentary formation, the composition has been modified greatly from the air or water that was originally used. To overcome problems such as borehole instability, a drilling fluid called mud was developed, consisting of water and bentonite clay. Mud has a number of properties such as its caking ability, its higher density, viscosity and its thixotropic properties, which make it particularly suitable for drilling deep and soft formations that would otherwise prove difficult to drill.

CHAPTER - 5

RESULTS AND DISCUSSION

5.1 Calculations for Delamination Factor

The damage zone that develops due to drilling hole was measured with the help of scanning electron microscopy (SEM). The delamination factor was determined by equation.

$$\mathbf{F_d = \frac{D_{max}}{d}}$$

Where F_d is the delamination factor, D_{max} is maximum diameter of drill damage zone and d is the diameter of drill bit. For present set of experiments, drill bit diameter is 10mm.

Table 5.1 Calculation of Delamination Factor

Exp No	Spindle Speed (RPM)	Feed (mm/min)	Maximum Diameter D_{max} (mm)	Diameter of drill bit d (mm)	F_d
1	1000	150	5.25	5	1.05
2	1000	200	5.7	5	1.14
3	1000	250	6.2	5	1.24
4	2000	150	5.45	5	1.09
5	2000	200	5.3	5	1.06
6	2000	250	5.85	5	1.17
7	3000	150	5.35	5	1.07
8	3000	200	5.65	5	1.13
9	3000	250	6.35	5	1.27

5.1.1 Calculation of S/N ratio for Delamination Factor

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for delamination factor SMALLER IS BETTER condition is opted. The equation for the calculation of S/N ratio for delamination factor is:

$$S/N_{SB} = -10 \log ((1/n) \Sigma y_i^2)$$

Table 5.2 Calculation of S/N ratio for Delamination factor

S.No	Delamination factor	Signal to noise ratio (db)
1	1.05	-0.42379
2	1.14	-1.1381
3	1.24	-1.86843
4	1.09	-0.74853
5	1.06	-0.50612
6	1.17	-1.36372
7	1.07	-0.58768
8	1.13	-1.06157
9	1.27	-2.07607

5.1.2 Calculation of Mean S/N ratio for Delamination Factor

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1+nf_2+nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

nf_1, nf_2, nf_3 are S/N ratio for factor f at level u

The factors which affect the machining parameters show in the table as their respective ranks. Rank of the parameters depends on the value of delta. If the delta value of one parameter is higher than the other that shows first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. Feed is the most effective machining parameter for delamination factor while spindle speed is least effective.

Table 5.3 Calculation of mean S/N ratio for Delamination Factor

Level	Spindle Speed	Feed
1	-1.1434	-0.5867
2	-0.8728	-0.9019
3	-1.2418	-1.7694
Delta	0.3690	1.1827
Rank	**2**	**1**

5.1.3 Analysis of Variance for Delamination Factor

Table 5.4 ANOVA of Delamination Factor

Source	DOF	SS	Adj MS	F Value	Contribution
Speed	2	0.004022	0.002011	1.38	8.10%
Feed	2	0.039756	0.019878	13.60	80.12%
Error	4	0.005844	0.001461		11.78%
Total	8	0.049622			100%

At least 95% confidence

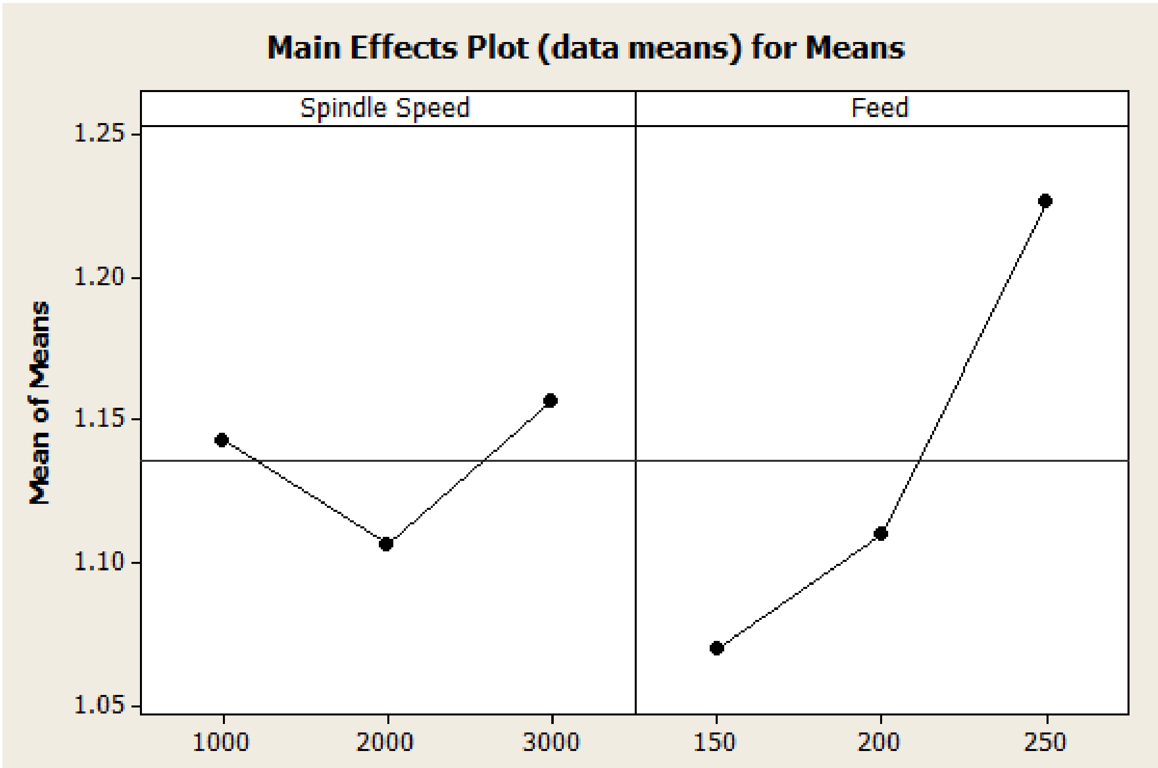

Figure 5.1 Mean Effect Plot for Delamination Factor

From the above graph it is clear that as we increase the spindle speed, the delamination factor tends to decrease initially till 2000 RPM. As the spindle speed is further increased, the delamination factor of the drilled hole start increasing. This is due to the fact that at higher spindle speed, the thermal gradients and drill speed make the drilled hole a bit larger than required. The feed is the most significant factor for delamination factor. Delamination factor increases with increase in feed and it shows that delamination factor follows an increasing trend with feed. As we increase the feed, the thickness of material to be removed increases. This increases the delamination effect and hence increased size holes are obtained. Minimum Delamination Factor is obtained at 2000 RPM spindle speed and 150 mm/min feed rate.

Optimal Levels of Parameters for Delamination Factor

For Delamination Factor the optimal level of parameters are as follows

Table 5.5 Optimal level of parameter for Delamination Factor

Process variables of factors		Optimum level
Speed	**RPM**	2000
Feed	**mm/min**	150

5.2 SEM Images of Delaminated Hole

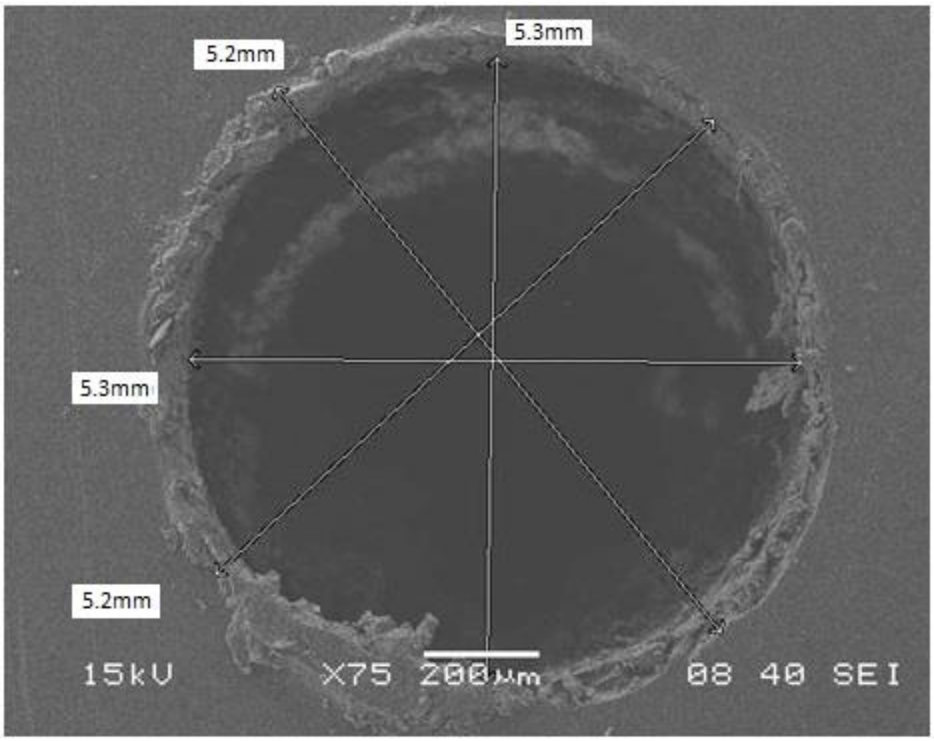

Figure 5.2 SEM image of Sample 1

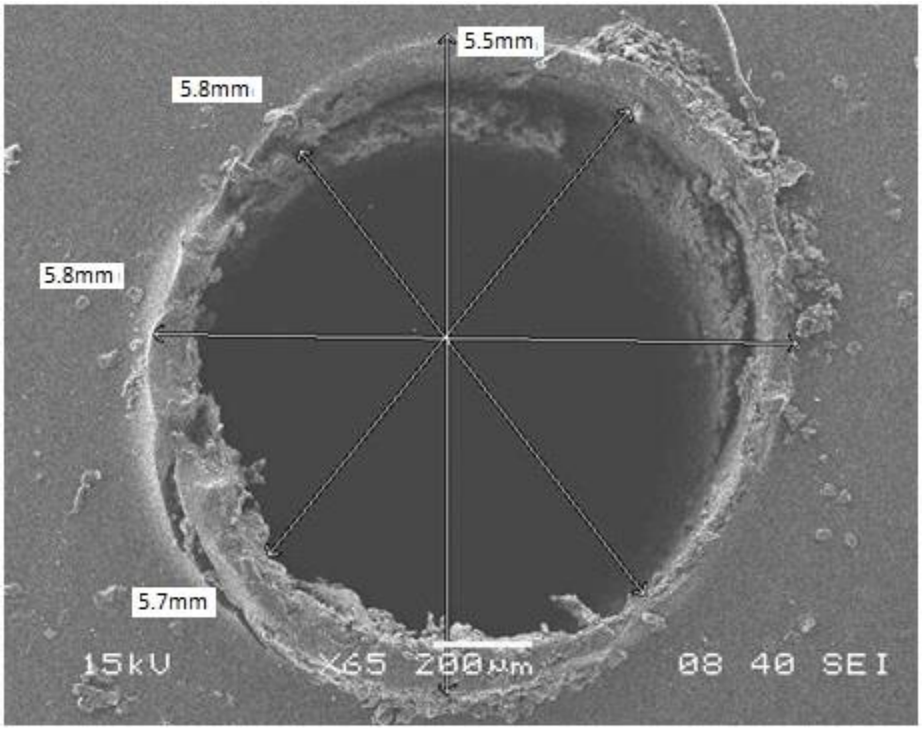

Figure 5.3 SEM image of Sample 2

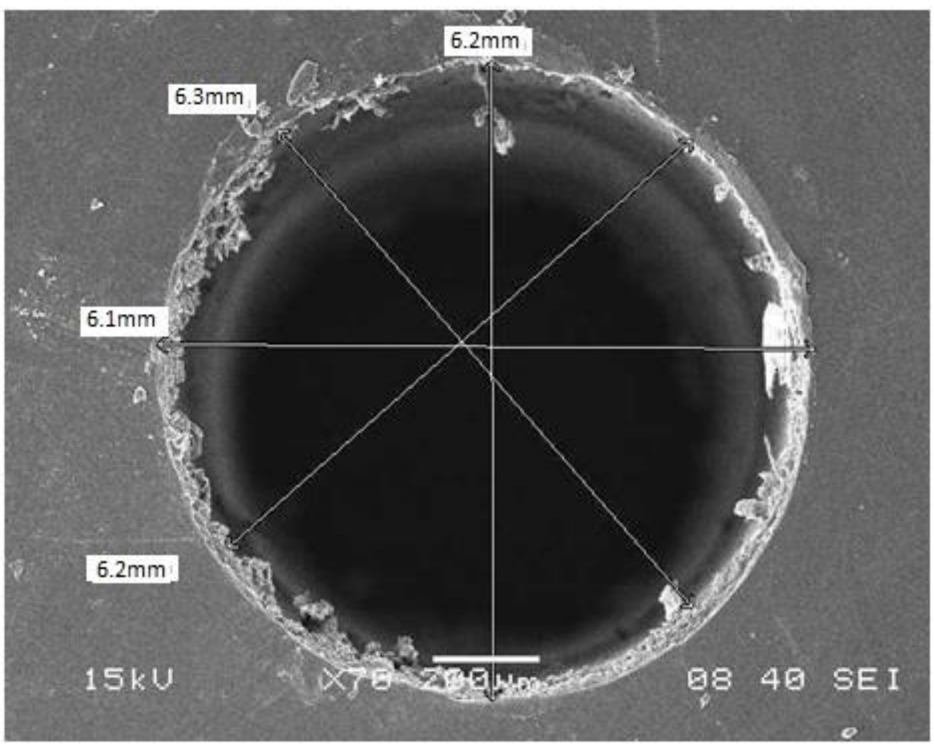

Figure 5.4 SEM image of Sample 3

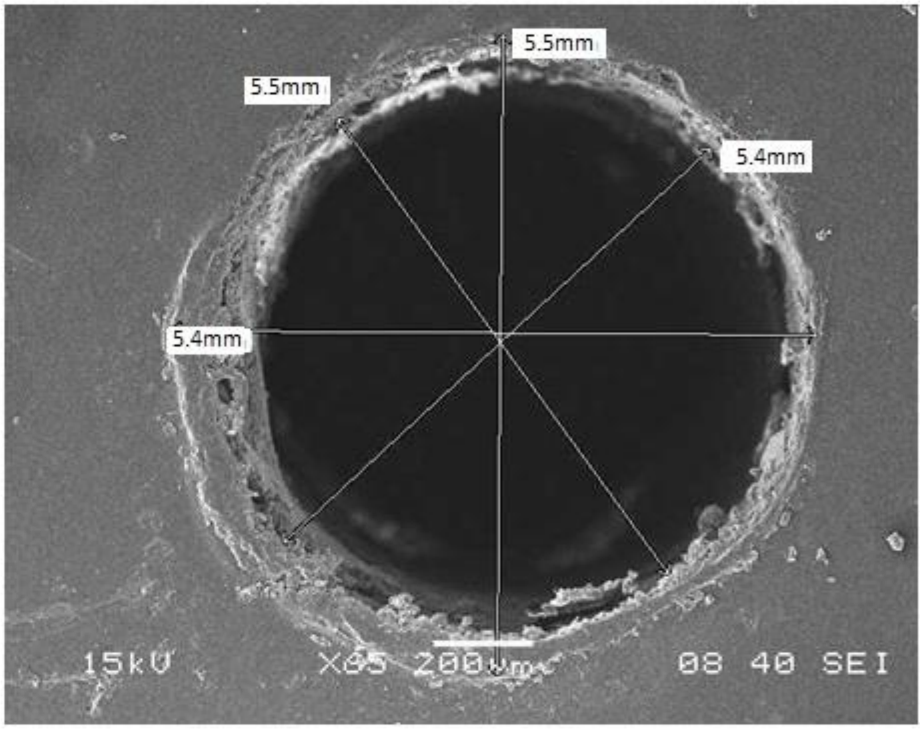

Figure 5.5 SEM image of Sample 4

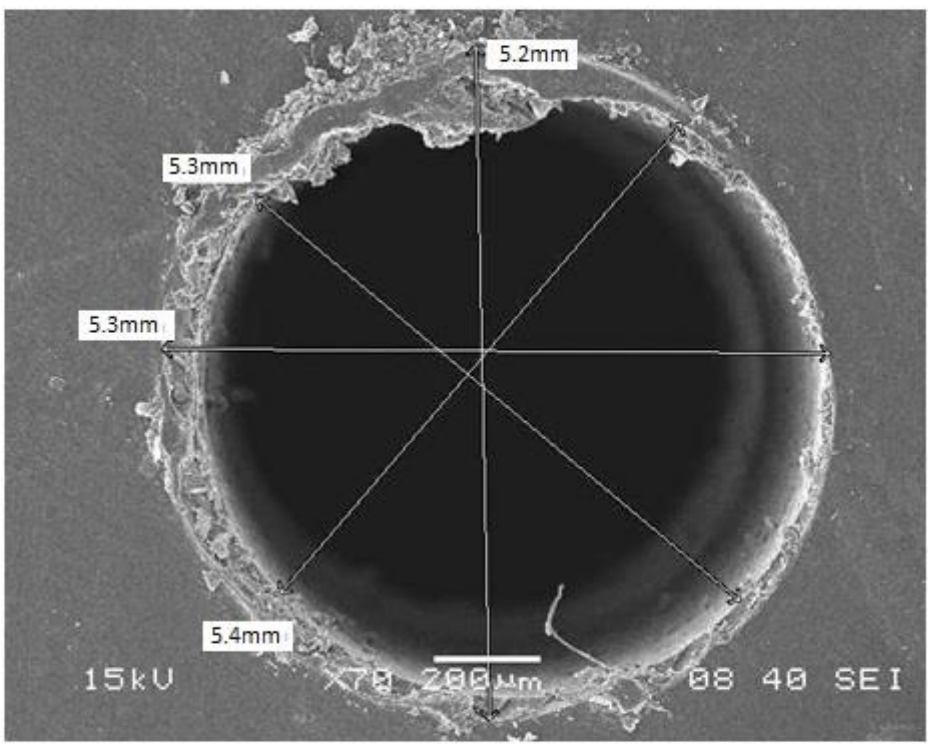

Figure 5.6 SEM image of Sample 5

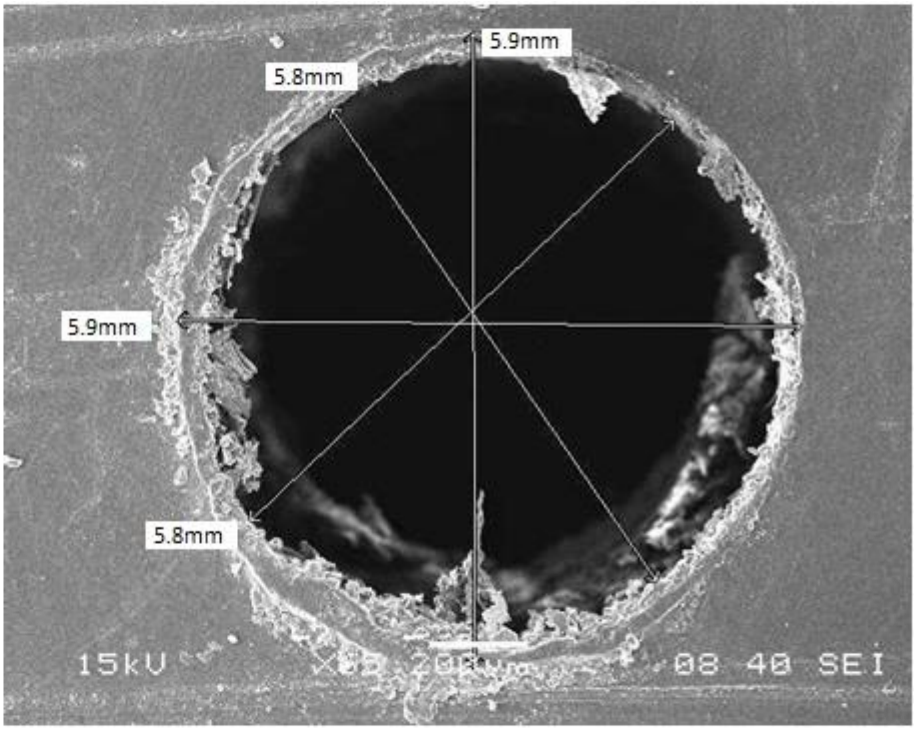

Figure 5.7 SEM image of Sample 6

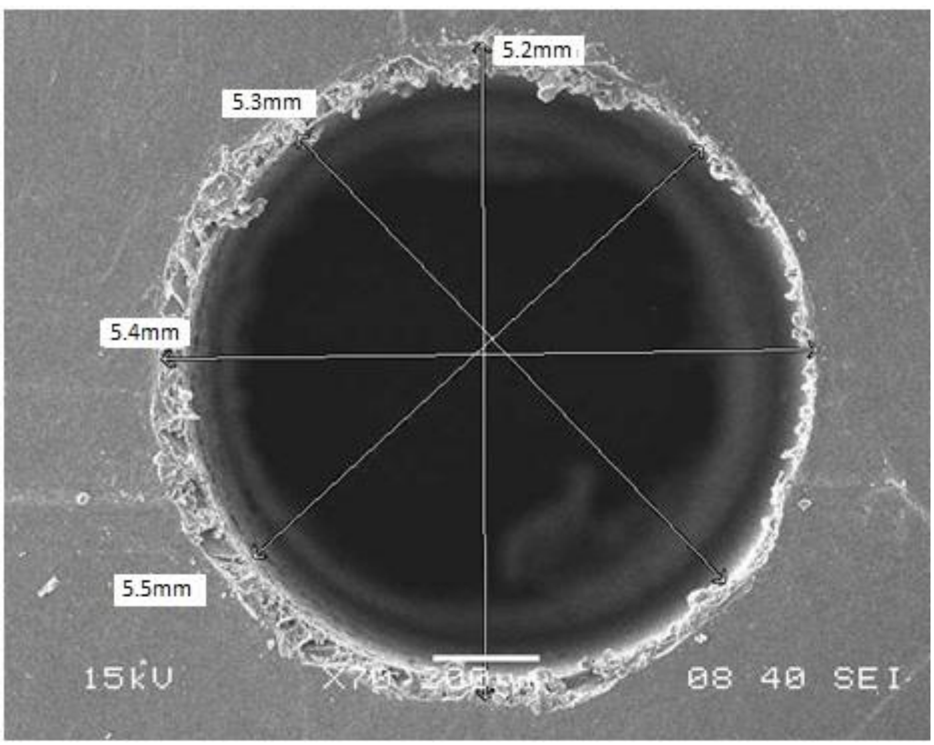

Figure 5.8 SEM image of Sample 7

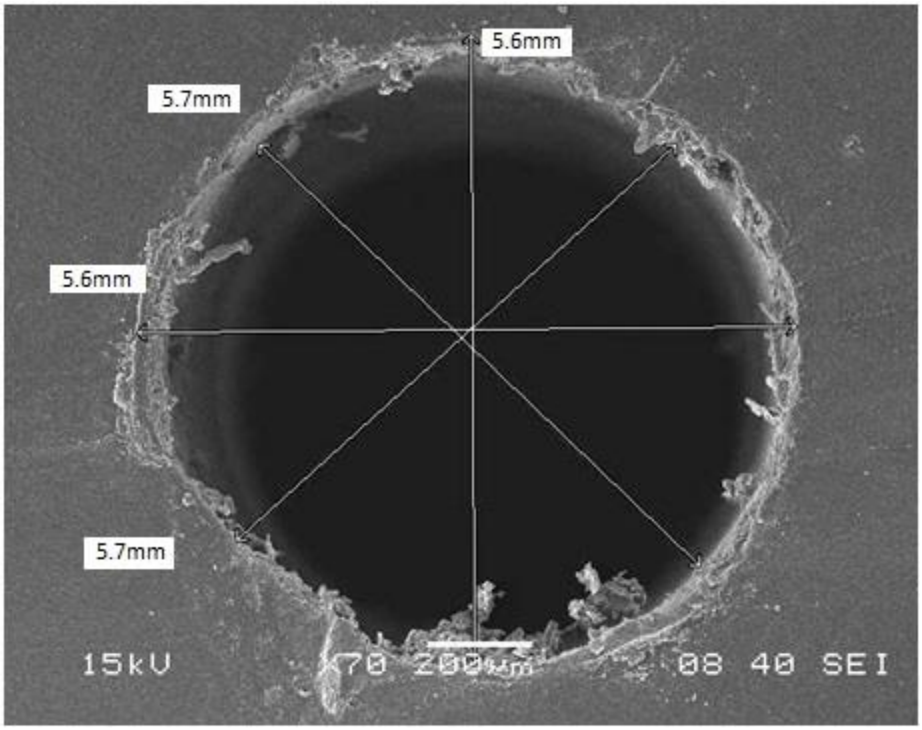

Figure 5.9 SEM image of Sample 8

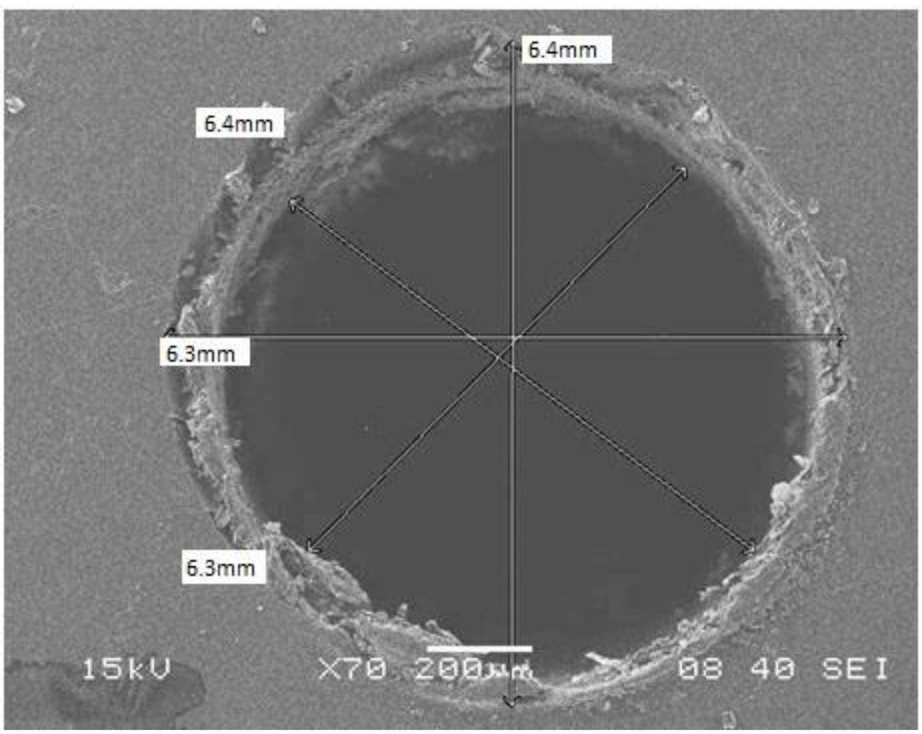

Figure 5.10 SEM image of Sample 9

5.3 Calculations for Surface Roughness

Table 5.6 shows the calculation of surface roughness varying with spindle speed and feed.

Table 5.6: Calculation for Surface Roughness

Exp. No	Spindle Speed (RPM)	Feed (mm/min)	Ra(μm)
1	1000	150	4.10
2	1000	200	4.43
3	1000	250	3.98
4	2000	150	4.14
5	2000	200	4.17
6	2000	250	3.71
7	3000	150	3.42
8	3000	200	3.64
9	3000	250	3.14

5.3.1 Calculation of S/N ratio for Surface Roughness

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for surface roughness SMALLER IS BETTER condition is opted. Smaller the surface roughness, better is the surface characteristics.

The equation for the calculation of S/N ratio for surface roughness is:

$$S/N_{SB} = -10 \log \left((1/n) \Sigma y_i^2 \right)$$

Table 5.7 Calculation of S/N ratio for Surface Roughness

S.No	Ra (µm)	Signal to noise ratio (db)
1	4.1	-12.2557
2	4.43	-12.9281
3	3.98	-11.9977
4	4.14	-12.34
5	4.17	-12.4027
6	3.71	-11.3875
7	3.42	-10.6805
8	3.64	-11.222
9	3.14	-9.9386

5.3.2 Calculation of Mean S/N ratio for Surface Roughness

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

nf_1, nf_2, nf_3 are S/N ratio for factor f at level u

Table 5.8 Calculation of mean S/N ratio for Surface Roughness

Level	Spindle Speed	Feed
1	-12.39	-11.76
2	-12.04	-12.18
3	-10.61	-11.11
Delta	1.78	1.08
Rank	**1**	**2**

5.3.3 Analysis of Variance for Surface Roughness

ANOVA for surface roughness is given in the following table-

Table 5.9 ANOVA of Surface Roughness

Source	DOF	SS	Adj MS	F Value	Contribution
Spindle Speed	2	0.98762	0.49381	62.03	72.92%
Feed	2	0.33482	0.16741	21.03	24.72%
Error	4	0.03184	0.00796		2.36%
Total	8	1.35429			100%

At least 95% confidence

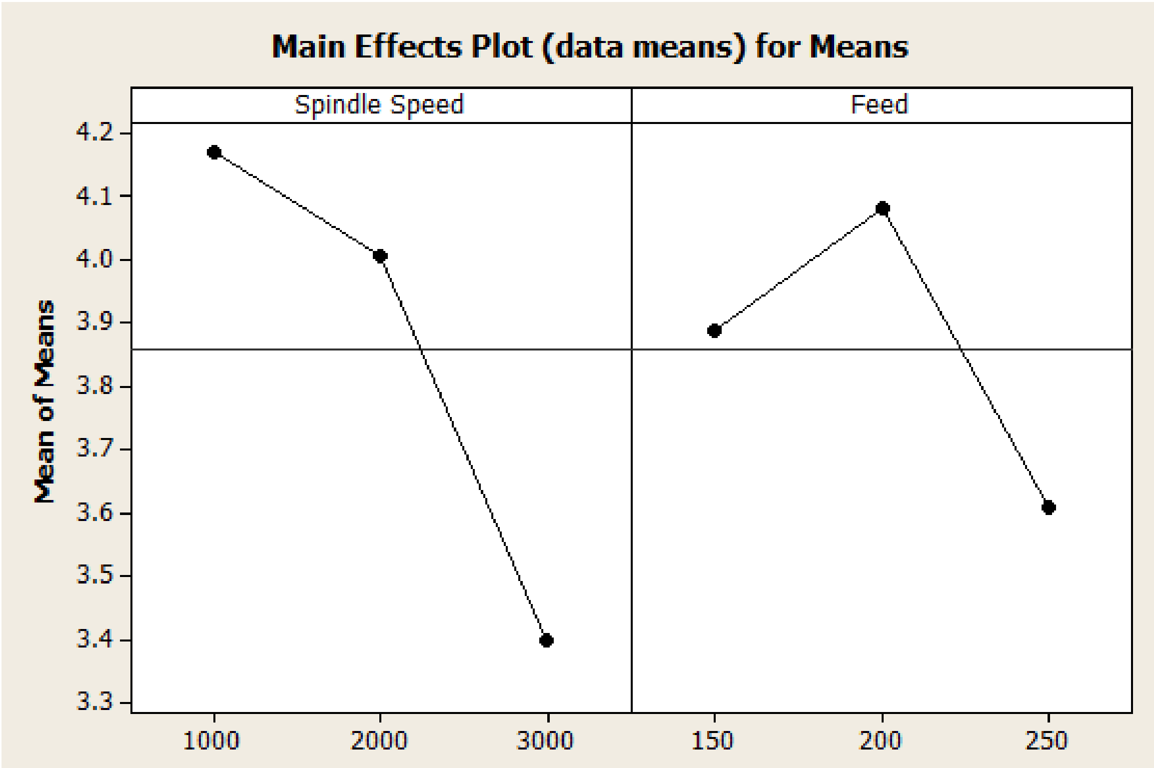

Figure 5.11 Main Effect Plot for Surface Roughness

The above graph shows the effect of input parameters on surface roughness. From the graphs it is seen that the surface finish improves with increasing the level of machining parameters. By increasing the spindle speed, the surface roughness increases and the surface finish starts to improve. A finished surface is generated as we increase the spindle speed to the higher levels. Spindle speed is the most crucial factor for surface roughness and ANOVA also shows that it contributes 72.92% towards surface roughness. In case of feed rate, it also affects the surface roughness in similar fashion. The surface initially degrades with the increase in feed rate upto 200 mm/min. But with further increase in the value of feed rate, surface finish start to improve. Feed rate has a contribution of 24.72% towards surface roughness. Lowest surface roughness is obtained at 3000 RPM spindle speed and 250 mm/min feed rate

Optimal Levels of Parameters for Surface Roughness

For Surface Roughness the optimal level of parameters are as follows

Table 5.10 Optimal level of parameter for Surface Roughness

Process variables of factors		Optimum level
Speed	**RPM**	3000
Feed	**mm/min**	250

5.4 Confirmation Test

Confirmation tests have been performed for Delamination Factor and Surface Roughness with their optimum levels of process variables.

Table 5.11: Confirmation of expected and actual values of Delamination Factor

Exp No.	Optimum Drilling Parameters		Delamination Factor	
	Spindle Speed (RPM)	Feed (mm/min)	Actual	Expected
1	2000	150	1.09	1.07
			Error (%)	1.83%

Table 5.12: Confirmation of expected and actual values of Surface Roughness

Exp No.	Optimum Drilling Parameters		Surface Roughness	
	Spindle Speed (RPM)	Feed (mm/min)	Actual	Expected
1	3000	250	3.14	3.06
			Error (%)	2.55%

CHAPTER – 6

CONCLUSION

6.1 Conclusion

This experimental study described the optimization of input machining parameters of drilling machine viz. spindle speed and feed rate during drilling of Aluminium 6061 using HSS tool with Taguchi method for designing the experiments. Factors with different levels were found to play significant role in drilling operation for minimization of Delamination Factor and Surface Roughness.

Based on above work following conclusions are made:

- As we increase the spindle speed, the Delamination Factor tends to decrease initially till 2000 RPM. As the spindle speed is further increased, the delamination factor of the drilled hole start increasing. This is due to the fact that at higher spindle speed, the thermal gradients and drill speed make the drilled hole a bit larger than required.
- The feed is the most significant factor for delamination factor. Delamination factor increases with increase in feed and it shows that delamination factor follows an increasing trend with feed.
- As we increase the feed, the thickness of material to be removed increases. This increases the delamination effect and hence increased size holes are obtained.
- Minimum Delamination Factor is obtained at 2000 RPM spindle speed and 150 mm/min feed rate.

- The surface finish improves with increasing the level of machining parameters. By increasing the spindle speed, the surface roughness increases and the surface finish starts to improve. A finished surface is generated as we increase the spindle speed to the higher levels. Spindle speed is the most crucial factor for surface roughness and ANOVA also shows that it contributes 72.92% towards surface roughness.
- In case of feed rate, it also affects the surface roughness in similar fashion. The surface initially degrades with the increase in feed rate upto 200 mm/min. But with further increase in the value of feed rate, surface finish start to improve. Feed rate has a contribution of 24.72% towards surface roughness.
- Lowest surface roughness is obtained at 3000 RPM spindle speed and 250 mm/min feed rate

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