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Optimization of Process parameters in formdrilling of Al 8011 using Taguchi Analysis

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Abstract: This paper aims at optimizing the process parameters of formdrilling using Taguchi method and applying analysis of variance (ANOVA) for better surface quality of hole drilled using formdrilling method and to check the accuracy of hole drilled after formdrilling of Al 8011 alloy. The response parameters of hole drilled like surface roughness, accuracy are analyzed under varying cutting speeds, feed rates, and depth of drilling (material thickness/hole depth) and with different coolants. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA) were employed to find the optimal levels, combinations of process parameters and to analyze the influence of the formdrilling parameters on surface finish and hole diameter accuracy. Confirmation tests with the optimal levels of machining parameters are carried out in order to find the effectiveness of the Taguchi's optimization method.

Keywords — Formdrilling, Al 8011, Taguchi, ANOVA, Accuracy, Surface Roughness, Optimization. S/N ratio, Orthogonal Array

I. INTRODUCTION

Beyond the traditional machining processes, formdrilling is one of the most important metal cutting operations among all metal cutting operations. Formdrilling is a bush making process applied to thin walled products contrary to conventional drilling. Formdrilling also called as Thermal drilling, chip less drilling process, Friction drilling. In friction drilling there is no material removal but there is displacement of material and this is a no-chip or chip free machining process. The bush is formed from the parent material which is subjected to friction heating, but at the end bush material has a good surface finish because of the occurrence of dynamic recrystallization. In this process, generally hard drills are used extensively. On the other hand, as work material Al8011 is considered and investigated because of its importance in industrial applications. B.Latha Shankar [1] analyzed by machining of Al8011 upon adding graphite particles and tested their tensile strength, hardness, Machinability of Aluminum alloys which are used in many industries to make different products because of its wear resistance property. Dr. H. K. Shivanand [2] developed and characterized Wear Properties of Aluminum 8011 Hybrid Metal Matrix Composites and shown its good mechanical properties and is significant to the world economy too. According to this the components made from aluminum and aluminum alloys are vitally used in aerospace industry and are very important in other areas like transportation and building in which durability, strength, and light weight are desired. Although aluminum alloys are relatively soft materials that can be possible to machine easily, the material temperatures rise under dry conditions. Girish.G [3] attempted to study the influence of Friction Stir Welding process parameters on AA 8011 alloy and to optimize the process parameters by taguchi method. According to his work tool speed, traverse speed has influence. That's why to check the influence of tool speed in formdrilling as an input parameter considered for present work. Coming to the response variables (outputs) of interest they are important quality characteristics of holes in view of this formdrilling process. These include the accuracy of hole diameter, surface roughness inside the hole and diametrical error. In this process, drill performance and hole quality are mainly investigated and these are dependent on the cutting parameters, drilling tools and its material. Because of this, researchers have been focused on determining the best machining process in drilling technologies specifically. Many numerical and experimental techniques have been developed and used by researchers in the past days in order to predict and determine significant parameters which affect the formdrilling process and hole accuracy. Han-Ming Chowa [4] studied and developed a new type of thermal friction drill with sintered carbide. It then can be applied to drill the Austenite stainless steel (AISI 304) .The Taguchi method was applied to explore how the different parameters such as drill shape and

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friction angle, friction contact area ratio, feed rate, and drilling speed would affect the response parameter. In present work in addition to investigating the effect of process parameters, surface quality of hole in the formdrilling processes also analyzed through response parameters. In this study, the settings of formdrilling parameters were determined by using Taguchi's experimental design method, Design of Experiments (DOE). M. Balaji [5] performed Optimization of Cutting Parameters in Drilling of AISI 304 Stainless Steel Using Taguchi and ANOVA and concluded that helix angles have significant effect on surface finish Whereas Nisha Tamta [6] performed optimization of process parameter for Al alloy 6082 by using taguchi method to get better surface roughness in drilling. According these authors speed followed by feed has the significant influence on surface roughness in drilling. Therefore for in present work for formdrilling these parameters included as inputs and analyzed. Sara A. El-Bahloul [7], Sushant Sunil Patil [9] were concentrated particularly on thermal drilling i.e., formdrilling performed and then applied taguchi optimization method to optimize process parameters but the difference in these two works is that Sara A. El-Bahloul applied fuzzy logic for further analysis whereas Sushant Sunil Patil compared two materials mild steel, Aluminium upon formdrlling. S.Dasgupta [8] extended his work even for turning, optimization of process parameters for better tool life. According this speed, feed and depth of cut has influence and given scope to apply ANOVA after taguchi method for futher analysis. From these works it is observed that taguchi has prominent role in optimizing. Vinayak Samleti [10], V.N.Gaitonde et al. [11] was also performed multi objective optimization. But variation among these works is that influence of burr size is considered in the work of V. N. Gaitonde. According this work larger point angles gives lesser burr size and concluded that cutting speed, feed and lip clearance angle are independent of drill diameter. Through the thorough analysis of reviews for present work taguchi optimization considered and orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, Analysis of variance (ANOVA) are employed to find optimal level [12], optimal combination of process parameters and to analyze effect of formdrilling parameters on surface roughness and accuracy of hole was determined practically. Confirmation tests were carried out for optimal levels of process parameters in order to know the effectiveness of Taguchi optimization method.

II. METHODOLOGY

A. Taguchi Analysis

Taguchi methods are the best additions to the toolkit of design, process, and manufacturing engineers, and Quality Assurance (QA) experts. In contrast to Statistical Process Control (SPC), which attempts to control the factors that adversely affect the quality of production, Taguchi methods focus on design the development of 'superior' performance designs' (of both products and manufacturing processes) to deliver quality at higher levels. Taguchi methods have rapidly attained prominence because, wherever they have been applied, they have led to major reductions in product/process development lead time. It helps in rapidly improving the manufacturability also. Essentially, traditional experimental design procedures are too complicated and uneasy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve such problems, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with less number of experiments. The greatest advantage of this method is the saving of effort in conducting experiments, saving experimental time, reducing the cost, and discovering significant factors quicker manner. Taguchi's robust design method is a powerful tool for the design of a high quality system. The Taguchi method uses S/N ratio to measure the variations of experimental design. The word signal says the desirable value and the word noise says the undesirable value. S/N ratios were calculated for surface roughness and amplitude of drill bit vibration using smaller is the best characteristic. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on surface roughness values. In this way, the optimal levels of process parameters can be estimated. The steps involved in Taguchi optimization was presented in the Fig.1.

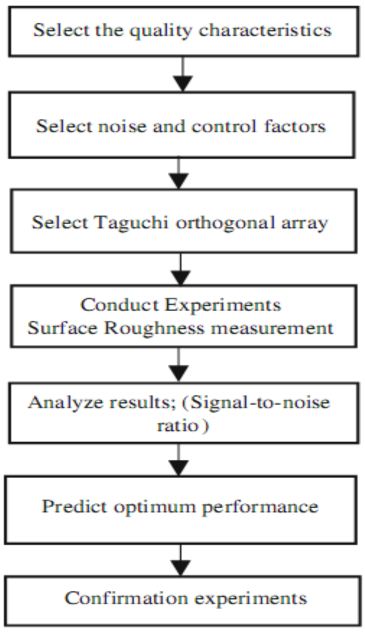

Fig 1.Steps involved in Taguchi's optimization method

B. Orthogonal Array Experiment

Use of an orthogonal array (OA) to reduce the number of experimental runs for determination of optimal cutting parameters is presented. The orthogonal array can be thought of as a distillation mechanism through which the engineers experiment passes. The array allows the engineer to vary multiple variables at one time and obtain the effects which that set of variables has an average and the dispersion. Taguchi employs design experiments using specially constructed table known as "Orthogonal Arrays (OA)". Orthogonal Arrays (OA) are a special set of Latin squares, constructed by Taguchi to layout the design experiments. The orthogonal array for present work is listed in the below Table .1. An orthogonal Array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. Orthogonal

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Arrays are employed to study the effect of several control factors. To take the orthogonal array in Minitab (open Minitab menu > Stat > Taguchi > Create Taguchi Design). Orthogonal arrays are not unique to Taguchi. Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects. In Minitab Taguchi Design > Mixed Level Design>Number of factors, select the factors in Taguchi Design Factor. In this the columns are mutually orthogonal. That is for any pair of columns, all combination of factors occurs and they occur an equal number of times. Here there are 4 parameters A, B, C, D and A is with 6 levels, remaining B, C, D are each at three levels. This is called an

L_{18} Mixed level design of experiments (DOE). In this 18 indicates number of rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus L18 (Mixed Level Design) means that eighteen experiments are to be carried out to study variables. There are greater savings for larger arrays.

Table.1 L18 Orthogonal array

Exp. No	Cutting Parameter Level			
	A Drilling Speed	B Feed	C Hole Depth	D Coolant
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	2
5	2	2	2	3
6	2	3	3	1
7	3	1	2	1
8	3	2	3	2
9	3	3	1	3
10	4	1	3	3
11	4	2	1	1
12	4	3	2	2
13	5	1	2	3
14	5	2	3	1
15	5	3	1	2
16	6	1	3	2
17	6	2	1	3
18	6	3	2	1

The Signal to noise concept is closely related to the robustness of a product design. A robust design or product delivers strong 'signal'. It performs its expected function and can cope with variations ("noise"), both internal and external. In signal to noise ratio signal represents the desirable value and noise represents the undesirable value.

The Advantages are as follows:

1. S/N ratios can be used to get closer to a given target value or to reduce variation in the product's quality characteristics.
2. S/N ratio used to measure controllable factors that can have such a negative effect on the performance of the design. They lead to optimum through monotonic function.
3. S/N ratios can be used to quantify the quality.

The formulae for signal to noise ratio are designed so that an experiment can always select the largest factor level setting to optimize the quality characteristic of an experiment. There are three signals to noise ratios of common interest for optimization of static problems, they are:

(a) Smaller -The -Better
(b) Larger- The- Better
(c) Nominal-The – Better

a) Smaller -The –Better:

To get the better quality the output parameters should be low. For this Smaller S/N ratio are considered.

$$\frac{S}{N} = -10 \log \left[\frac{\Sigma y_i^2}{n}\right]$$ Where i= 1, 2,….n

b) Larger- The- Better:

To get the better quality the output parameters should be high. For this larger S/N ratio are considered.

$$\frac{S}{N} = -10 \log \left[\frac{1}{n}\sum \frac{1}{y_i^2}\right],$$ where i= 1, 2,….n

c) Nominal -The- Better:

To get the better quality the output parameters should be nominal. For this Nominal S/N are considered.

$$\frac{S}{N} = 10 \log \left[\frac{y_i^2}{s^2}\right],$$ where i= 1, 2,….n

For the present work to get better surface roughness 'smaller-the- better' optimization static is considered. In addition to the Taguchi analysis using ANOVA also applied. Analysis of Variance (ANOVA) is a statistical tool which is used to discuss the relative importance of the entire control factor. To find the contribution of each parameter ANOVA gives best possible results. F-test proposed by Fisher is used as an auxiliary tool of inspection in this technique. If larger the value of F-test the respective parameter is the more dominant one on the response variable.

III. EXPERIMENTATION

A. Material, Machine Tool Selection

To perform formdrilling work material selection, machine tool selection plays an important role in addition to the selection of process parameters. For present work the work material Al8011 alloy is considered, the composition of Al8011 is shown in below Table.2. Industrial application point of view, Aluminium alloys in particular are ideal candidates because of their favorable engineering properties. Being lightweight Aluminium alloys are widely used in aircraft, defense and automotive industries.

Table.2 Composition of Al 8011

Element	Weight %
Al	98.1
Fe	0.6
Si	0.5
Mn	0.2
Cu	0.1
Zn	0.1
Ti	0.08

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Cr	0.05
Mg	0.05
Others	0.22

On the other hand, the Machine tool considered is CNC Vertical Machining centre JV-55 which is compatible to perform formdrilling where high speeds (Maximum possible speed: 6000 rpm) are necessary.

B. Selection of process parameters and their levels

According to Taguchi Design of experiments here four parameters Speed, Feed, depth of drilling, Coolant were considered. Among these Speed is with six levels, remaining feed, depth of drilling, Coolants are each at three levels. This is called an L_{18} design. In this 18 indicates number of rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus L_{18} (Mixed Level Design) means that eighteen experiments are to be carried out to study variables. The factor information is listed in the below Table .3.

Table.3 Factor Information

Parameter		Speed (rpm)	Feed (mm/rev)	Drilling Depth (mm)	Coolant
Level	1	2000	0.1	2	Dry
	2	2500	0.2	3	Vegetable oil
	3	3000	0.3	4	Soluble oil+ water (1:10)
	4	3500	-	-	-
	5	4000	-	-	-
	6	4500	-	-	-

Generally, drilling operations are carried out at normal speeds. Whereas, formdrilling requires high speeds for better performance. To meet the requirements of the form drilling LMW JV-55 Computer Numerical Control (CNC) Machine is adopted. Selection of tool plays a major role to perform formdrilling operation. To machine Al8011 material the tool considered is Tungsten Carbide (WC) which has good wear resistance and strength. The specification of the tool is mentioned below according to the nomenclature of the tool which is specified in Fig.2.

Specification of Formdrill:

Tool material: Tungsten Carbide
Diameter (D) = 4.1mm; $\alpha = 90^0$; $\beta = 36^0$
Shank region = 12 mm
Shoulder region = 7mm
Cylindrical region = 6mm
Conical region = 4mm
Centre region = 1mm
Total height of tool = 30mm

Fig 2.Formdrill

The work material was held in a vice on the bed of the machine and the tool was held by a standard collets tool holder. A sharp point is avoided and a small flat surface is provided on the cone head to initiate friction heat, as the cone penetrates into work the metal gives way due to plastic deformation and the diameter gradually increases. During drilling to measure the temperature at the mating zone of tool and work material infrared thermometer is used. The formdrilling is performed using CNC JV-55 machining center, through automated speed, feeds as inputs. The setup of the formdrilling is shown in Fig.3and Fig.4. Using the setup Al8011 is drilled according to the design of experiments L_{18} of mixed factorial design. The program to perform form drilling is manually fed into the control panel of LMW JV-55 machining center and checked using different drilling cycles to perform operation correctly without any canned cycles. The program is fed into the Programming window may be manually or copied from any other external storage devices.

Fig.3 Formdrilling setup

Fig.4 Enlarged view of the setup

After the entire setup, run the formdrilling program then the tool mates with the work material, the friction force on the contact surface produces heat and softens the work-

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material. The tool is then extruded into the work piece, pushes the softened work-material sideward, and pierces through the work piece. Once the tool tip penetrates into the work piece, tool moves further forward to push aside more work material and form the bushing using the cylindrical part of the tool. The shoulder of the tool may contact with the work piece to trim or collar the extruded burr on the bushing. Finally, the tool retracts and leaves a hole with a bushing on the work piece in addition to petal formation underneath of work material. After machining the work material were obtained as shown in Fig.5.

Out of various measures of output responses the surface roughness is majorly considered. Among many measures of surface roughness parameters namely roughness average (R_a), Root mean square (rms) roughness (Rq), and maximum peak to valley roughness (R_y or R_{max}) the parameter roughness average (Ra), which is most widely used in industry was selected in this study. Eighteen experiments based on orthogonal array L_{18} were conducted for different settings of cutting fluid, speed, feed and hole depth. The surface roughness of all the specimens was measured using the Taylor Hobson Surf Com instrument (shown in Fig.6) for a sampling length of 3mm and the measured R_a values are listed in the Table.5.

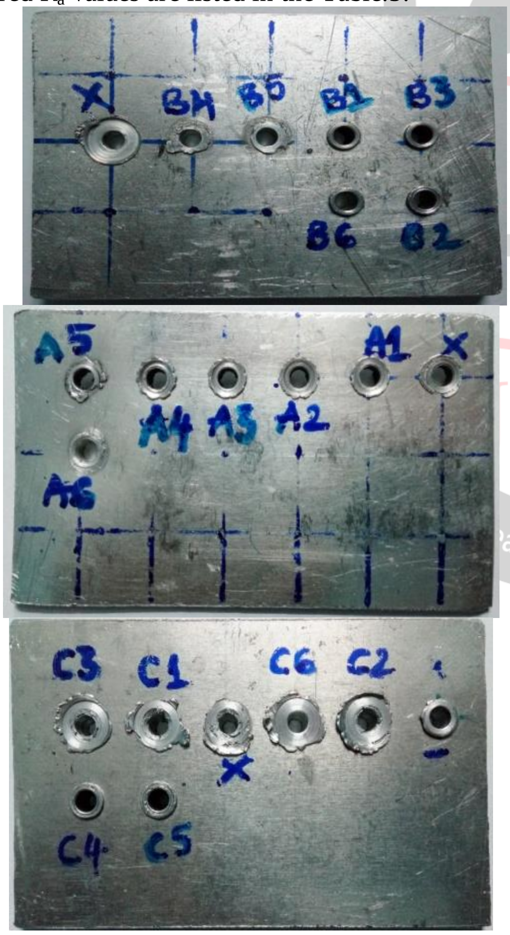

Fig.5 Work material after formdrilling

Fig.6 Measurement of Surface roughness

After the experimental runs the work material checked for surface roughness and diametrical error by considering at three places and averages are calculated and their averages are listed in the Table.5 as surface roughness, diametrical error and obtained results are analyzed, optimized using Taguchi Analysis.

Table.4 L18 Orthogonal Array of Inputs

Trial. No	A Drilling Speed (rpm)	B Feed (mm/rev)	C Hole Depth (mm)	D Coolant Type
1	2000	0.1	2	Dry
2	2000	0.2	3	Vegetable oil
3	2000	0.3	4	Soluble oil Mixture
4	2500	0.1	2	Vegetable oil
5	2500	0.2	3	Soluble oil Mixture
6	2500	0.3	4	Dry
7	3000	0.1	3	Dry
8	3000	0.2	4	Vegetable oil
9	3000	0.3	2	Soluble oil Mixture
10	3500	0.1	4	Soluble oil Mixture
11	3500	0.2	2	Dry
12	3500	0.3	3	Vegetable oil
13	4000	0.1	3	Soluble oil Mixture
14	4000	0.2	4	Dry
15	4000	0.3	2	Vegetable oil
16	4500	0.1	4	Vegetable oil
17	4500	0.2	2	Soluble oil Mixture
18	4500	0.3	3	Dry

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IV. RESULTS AND DISCUSSION

The output responses were collected during formdrilling experiments and then optimization technique is applied to optimize the formdrilling process parameters to get better surface finish. The Table.4 gives information of output responses, Signal to Noise ratios (S/N ratio) of all the experimental runs. The S/N ratio describes about the level of a desired signal to the level of background noise. In this table in addition to the surface roughness, diametrical error also determined and listed.

Table.5 L18 Orthogonal Array with Output Responses

Trial. No	A Spindle Speed (rpm)	B Feed (mm/rev)	C Hole Depth (mm)	D Coolant Type	Diametrical error (mm)	Surface Roughness (μm)	S/N Ratio for Surface Roughness
1	2000	0.1	2	1	0.04	0.24	12.39
2	2000	0.2	3	2	0.03	0.24	12.39
3	2000	0.3	4	3	-0.02	1.21	-1.65
4	2500	0.1	2	2	0.03	0.36	8.87
5	2500	0.2	3	3	0.04	0.23	12.76
6	2500	0.3	4	1	0.01	1.06	-0.50
7	3000	0.1	3	1	0.02	1.48	-3.40
8	3000	0.2	4	2	0.04	0.21	13.55
9	3000	0.3	2	3	0.01	1.32	-2.41
10	3500	0.1	4	3	0.03	0.48	6.37
11	3500	0.2	2	1	0.01	0.87	1.20
12	3500	0.3	3	2	0.04	0.66	3.60
13	4000	0.1	3	3	0.01	0.79	2.04
14	4000	0.2	4	1	0.00	0.86	1.31
15	4000	0.3	2	2	0.02	0.89	1.01
16	4500	0.1	4	2	-0.08	1.26	-2.01
17	4500	0.2	2	3	0.02	0.50	6.02
18	4500	0.3	3	1	0.00	0.55	5.19

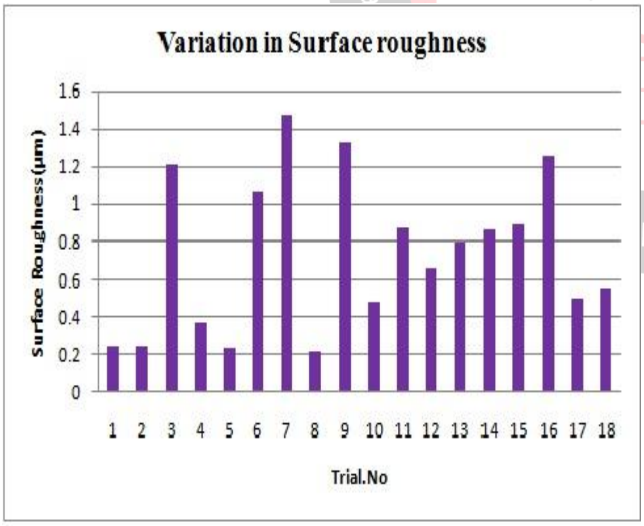

Fig.7 Variation in Surface roughness

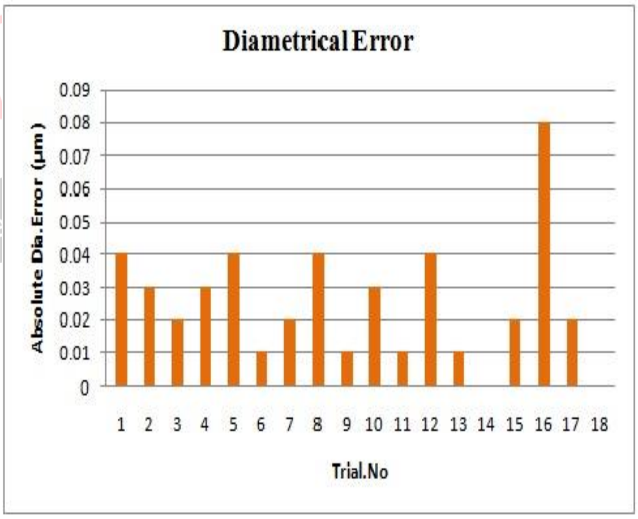

Fig.8 Variation in diametrical error

The variations of surface roughness, diametrical error are analyzed and presented as histograms in the Fig.7 and Fig.8 respectively. Upon applying the Taguchi technique, obtained results were listed in the Table.6 which is obtained in terms of ranks based on the influence of the process parameters on response variables. In this study, ANOVA also performed to investigate the statistical significance of the process parameters affecting the surface roughness. The objective was to analyze the influence of spindle speed, feed rate and depth of cut, type of coolant on the total variance of the results. Table.7 shows the results of the ANOVA with the Surface roughness.

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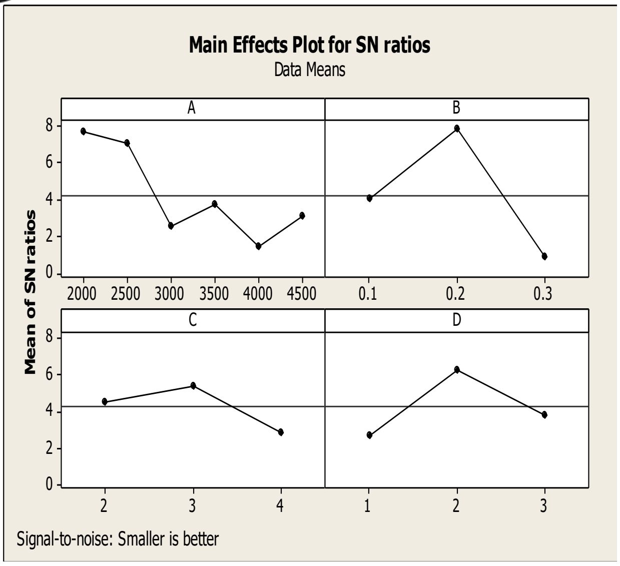

Fig.9 Response graph (S/N ratio) for Surface roughness

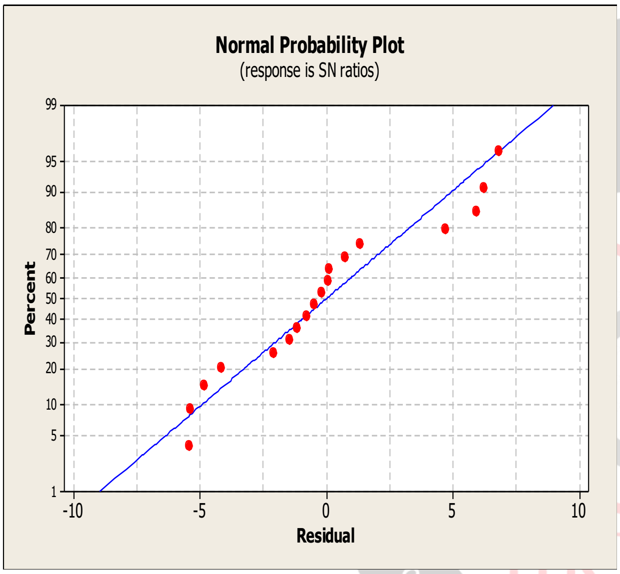

Fig.10 Normal probability plot for surface roughness

Fig.9 provides the information on main effects of process parameters based on the obtained S/N ratios. Fig.10 represents the normal probability plot for eighteen experimental runs. The confirmation tests are the final step in verifying the results obtained based on Taguchi's method of design approach. The optimal conditions are set for the significant factors and a selected number of experiments are run under specified cutting conditions.

Table.6 Response Table for Surface roughness

Level	Speed	Feed	Thickness	Coolant
1	0.5633	0.7683	0.6967	0.8433
2	0.5500	0.4850	0.6583	0.6033
3	1.0033	0.9483	0.8467	0.7550
4	0.6700	-	-	-
5	0.8467	-	-	-
6	0.7700	-	-	-
Delta	0.4533	0.4633	0.1883	0.2400
Rank	2	1	4	3

Table.7 Results of the analysis of variance

Parameter	DOF	Sum of Squares	Mean Squares	F-Value	P-Value	Influence (%)
Spindle Speed	5	0.4608	0.09217	0.37	0.849	15.96
Feed	2	0.6547	0.32736	1.33	0.332	22.68
Hole Depth	2	0.1189	0.05944	0.24	0.793	4.11
Coolant	2	0.1768	0.08841	0.36	0.712	6.12
Error	6	1.4752	0.24587	-	-	-
Total	17	2.8864	-	-	-	-

The confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental results. Therefore confirmation experiment was conducted by utilizing the levels of the optimal process parameters (A2B2C3D2) for surface finish in the formdrilling of Al8011 alloy.

V. Conclusions

In this study an investigation on surface roughness was performed based on the design of experiments by Taguchi

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method of optimization. The process parameters were optimized upon formdrilling and the experimental results were summarized and the following conclusions were drawn.

i. From Analysis of variance (ANOVA) results for the surface roughness major and minor influencing parameters were identified with their percentages of influence. Namely, the feed rate is the major influencing factor and this feed rate is influencing the surface roughness about 22.68% followed by the cutting speed with 15.96% and the lesser influencing parameter is depth of hole to be drilled with 4.11% on the surface roughness. There is a influence worth 15.6%, 6.12% by the speed, coolant utilized respectively on surface roughness in formdrilling.

ii. Among the significant parameters feed is the most significant parameter and least significant parameter is depth of drilling based on the F-test for surface roughness.

iii. Based on the signal to noise ratio results A3B2C3D2 combination settings are the optimal drilling parameters for surface roughness.

From Taguchi analysis results feed is the most influencing parameter which occupies 1st Rank followed by Speed with 2nd rank. When the results of ANOVA and Taguchi analysis were compared the obtained results were similar.

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