

# A STUDY OF TAGUCHI METHOD BASED OPTIMIZATION OF DRILLING PARAMETER IN DRY DRILLING OF AL 2014 ALLOY AT LOW SPEEDS

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## ABSTRACT

*Drilling operation is widely used in the aerospace, aircraft and automotive industries, although modern metal cutting methods have improved in the manufacturing industries, but conventional drilling still remains one of the most common machining. In this study, focuses on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and hole diameter. A number of drilling experiments were conducted using the L<sub>18</sub> orthogonal array on conventional drilling machine. The experiments were performed on AI 2014 alloy block using HSS twist drills under dry cutting conditions. The measured results were collected and analyzed with the help of the commercial software package MINITAB16. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting the surface roughness and hole diameter. The cutting tool, spindle speed and feed rate were selected as control factors. The main and interaction effect of the input variables on the predicted responses are investigated. The predicted values and measured values are fairly close.*

**KEYWORDS:** Dry drilling, Taguchi method, Analysis of Variance,

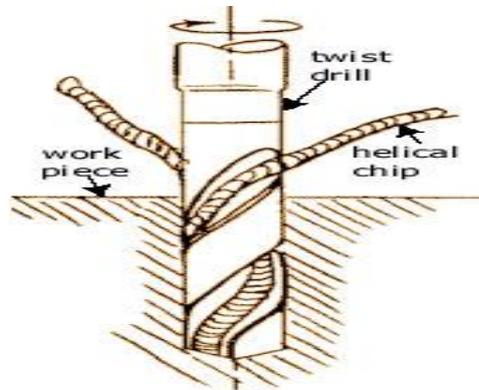
## I. INTRODUCTION

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. Drilling operation is widely used in the aerospace, aircraft and automotive industries, although modern metal cutting methods have improved in the manufacturing industries, but conventional drilling still remains one of the most common machining. The experiment was carried out on the basis of Taguchi's L<sub>18</sub> orthogonal array of experiments. The important input drilling parameters were chosen as spindle speed, point angle and feed rate and the responses namely. In order to minimize the values of all the above mentioned performance characteristics, an optimal combination of input drilling parameters is required. Taguchi optimization technique is used to for optimization of drilling parameters; ANOVA is used to find the highly influential drilling parameter(s) that contributes to a high quality product.

## II. DRILLING

Hole making is among the most important operations in manufacturing. Drilling is a major and common of hole making process. Drilling is the cutting process of using a drill bit in a drill to cut or enlarge holes in solid materials, such as wood or metal. Different tools and methods are used for drilling depending on the type of material, the size of the hole, the number of holes, and the time to

complete the operation. It is most frequently performed in material removal and is used as a preliminary step for many operations, such as reaming, tapping and boring. The cutting process in which a hole is originated or enlarged by means of a multipoint, fluted, end cutting tool. As the drill is rotated and advanced into the work piece, material is removed in the form of chips that move along the fluted shank of the drill. Figure 1 shows the drilling operation on to the work piece.

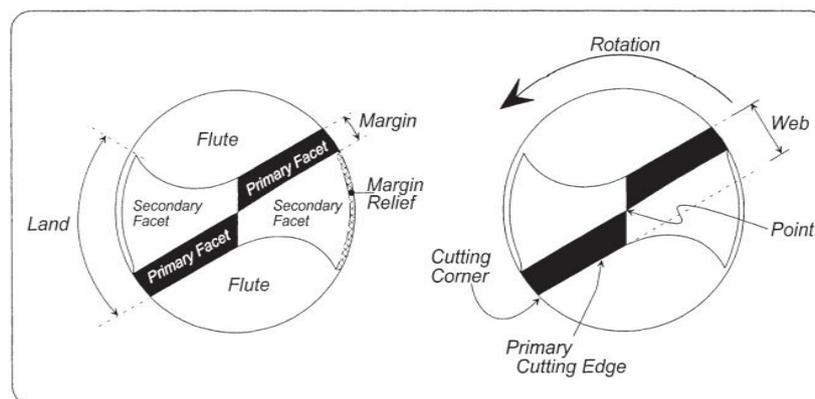


**Figure.1** Drilling operation on the work piece

Although long spiral chips usually result from drilling, adjustment of the feed rate can result in chips with a range of many different shapes and sizes. Material of work piece can also change the range of different chip shapes and sizes generally, the hole diameters produced by drilling are slightly larger than the drill diameter (oversize). The amount of oversize depends on the quality of the drill and also the equipment that used as well as the machinist skill.

### 2.1 GEOMETRIC ATTRIBUTES.

The geometry of a drill bit very much affects the way it behaves during drilling. (See Fig.2 for attribute nomenclatures.) The land is the area remaining after fluting. In order to reduce the amount of land that creates friction with the hole wall (thus generating heat), drill bits are margin relieved. The amount of land remaining in contact with the hole wall during drilling is referred to as the margin. The wider the margin, the greater the friction area [17] and the higher the drilling temperature, results in higher extent of heat-related.



**Figure.2** Drill bit geometry

The result of increasing the land mass and the web is a smaller flute area. Less flute space implies reduced amounts of available area to remove drilling debris, which again raises the drilling temperature. It is important to understand that some drill designs that are meant to increase strength (particularly in smaller-diameter drill bits, with the intent to reduce breakage) may include what are referred to as partial margin reliefs as shown in Fig.3. What this means is that when the drill bit is viewed from the point, a relieved margin is seen.

This type of design drill bit from the side reveals that the relief extends only part of the way, typically about one-fifth of the total flute length. The major drawback of this particular design is that it increases drilling temperatures resulting in increased heat-related drilled hole defects [18][19] (such as smear) and drill breakage due to packed margins.

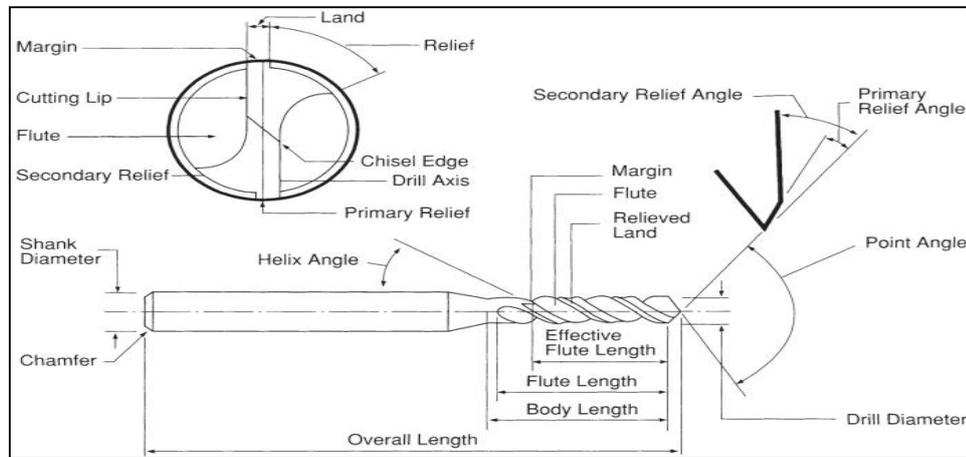


Figure.3 Drill tip attribute nomenclatures

### III. METHODOLOGY

#### 3.1 DESIGN OF EXPERIMENT (DOE)

Design of Experiment is a powerful approach to improve product design or improve process performance where it can be used to reduce cycle time required to develop new product or processes. Design experiment [1][3][4] is a test or series of test that the input variable (parameter) of a process is change so that observation and identifying corresponding changes in the output response can be verify. The result of the process is analyzed to find the optimum value or parameters that have a most significant effect to the process. The objectives of the experiment may include.

#### 3.2 ANALYSIS OF VARIANCE (ANOVA)

The Analysis Of Variance (ANOVA) is a powerful and common statistical procedure in the social sciences. It is the application to identify the effect of individual factors [10]. In statistics, ANOVA is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form ANOVA [2][4][5][8] gives a statistical test of whether the means of several groups are all equal, and therefore generalizes.

#### 3.3 FACTORIAL DESIGN

Factorial experiments permit researchers to study behavior under conditions in which independent variables, called in this context factors, are varied simultaneously. Thus, researchers can investigate the joint effect of two or more factors on a dependent variable. The factorial design [1][6][7] also facilitates the study of interactions, illuminating the effects of different conditions of the experiment on the identifiable subgroups of subjects participating in the experiment.

Table 1 shows the geometric presentation of contrast corresponding to the main effects and interaction in the  $2^3$  designs.

Table 1: Number of runs for  $2^k$  full factorial design

Number of factors	Number of runs
2	4
3	8
4	16

5	32
6	64
7	128

### 3.4 TAGUCHI APPROACH

Basically, experimental design methods were developed originally Fisher. However, classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases, to solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal – to – noise (S/N) ratio [13][14] to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., the – lower – better, the – higher – better, and the – nominal – better. The S/N ratio for each level of process parameter is compared based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistically significant with the S/N and ANOVA analyses, 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.

There are 3 Signal-to-Noise ratios [10][12] of common interest for optimization of Static Problems. The formulae for signal to noise ratio are designed so that an experimenter can always select the largest factor level setting to optimize the quality characteristic of an experiment. Therefore a method of calculating the Signal-To-Noise ratio we had gone for quality characteristic. They are

- Smaller-The-Better,
- Larger-The-Better,
- Nominal-The-Best.

#### The Smaller-The-Better

The Signal-To-Noise ratio for the Smaller-The-Better is:

S/N = -10 \*log (mean square of the response)

$$S / N = -10 \log_{10} \left( \frac{\sum y_i^2}{n} \right) \text{----- (1)}$$

#### The Larger-The-Better

The Signal-To-Noise ratio for the bigger-the-better is:

S/N = -10\*log (mean square of the inverse of the response)

$$S / N = -10 \log_{10} \left( \frac{1}{n} \sum \frac{1}{y_i^2} \right) \text{----- (2)}$$

Where n= number of measurements in trial/row, in this case

n=1, 2, ..., 9 and Y<sub>i</sub> is the i<sup>th</sup> measured value in a run/row. i =1, 2, ..., 27.

#### Nominal-the-Best

The S/N equation for the Nominal-The-Best is:

S/N = 10 \* log (the square of the mean divided by the variance)

$$S / N = 10 \log_{10} \left( \frac{\bar{y}^2}{s^2} \right) \text{----- (3)}$$

## IV. EXPERIMENTAL SETUP

In the present work, radial drilling machine is used to drill holes on Al 2014; the machine setup is shown in figure 4



Figure.4 Experimental Setup

#### 4.1 HIGH SPEED STEEL (HSS)

Advent of HSS in around 1905 made a breakthrough at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools. The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe.



Figure.5 HSS Tools

#### 4.2 WORK MATERIAL DETAILS

- Work material - AL2014
- Work material thickness - 12mm

#### 4.3 WORK MATERIAL PREPARATION

The work material is cut as required sizes of 100x50x12 mm<sup>3</sup>, from aluminum alloys raw stock with help of power hacksaw to perform drilling operation on them. The chemical composition and the mechanical properties of work materials are shown in Table 2

Table 2 Chemical composition of Aluminum alloy

Alloy	2014
Silicon (Si)	0.50 – 1.2
Ferrous (Fe)	0.7
Copper (Cu)	3.9 – 5.0
Manganese (Mn)	0.40 – 1.2
Magnesium (Mg)	0.20 – 0.8

Chromium (Cr)	0.10
Zinc (Zn)	0.25
Titanium (Ti)	0.15
Aluminium %	Remainder

#### 4.4 SURFACE FINISH MEASUREMENT

**Surftest SJ-201P:** Surftest SJ-201P (Portable surface roughness tester) instrument is widely used to measure the shape or form of components. A profile measurement device is usually based on a tactile measurement principle. The surface is measured by moving a stylus across the surface. As the stylus moves up and down along the surface, a transducer converts these movements into a signal which is then transformed into a roughness number and usually a visually displayed profile. Multiple profiles can often be combined to form a surface representation. Surftest SJ-201P is shown in figure 6.



Figure.6 Surftest SJ-201P

Table 3 Process parameters and their levels

Levels	Process parameters		
	point angle & Helix angle (A)	Spindle speed (rpm) (B)	Feed(mm\rev) (C)
1	90 <sup>0</sup> & 15 <sup>0</sup>	200	0.15
2	130 <sup>0</sup> & 20 <sup>0</sup>	250	0.3
3	-	300	0.36

Table 4 Experimental data for Al 2014 12mm thickness

S.No	Spindle Speed (rpm)	Feed (mm/rev)	Point angle & Helix angle (0 <sup>0</sup> )	Roughness (Ra) μm	Hole diameter (mm)
1	1	1	1	1.80	8.02
2	1	2	1	1.81	8.04
3	1	3	1	1.82	8.03
4	2	1	1	1.78	8.04
5	2	2	1	1.84	8.02
6	2	3	1	1.87	8.01
7	3	1	1	1.58	8.03
8	3	2	1	1.60	8.03
9	3	3	1	1.63	8.02

10	1	1	2	1.61	8.21
11	1	2	2	1.63	8.21
12	1	3	2	1.70	8.21
13	2	1	2	1.67	8.21
14	2	2	2	1.82	8.23
15	2	3	2	1.83	8.23
16	3	1	2	1.58	8.22
17	3	2	2	1.63	8.23
18	3	3	2	1.70	8.22

## V. ANALYSIS OF RESULTS

**Table 5** Roughness values and S/N ratio's values for the experiments of Al 1014 (12mm thickness)

S.No	Spindle Speed (rpm)	Feed (mm/rev)	Point angle & Helix angle (0°)	S/N Response value (dB) for Roughness(Ra)	S/N Response value (dB) for Hole diameter
1	1	1	1	-5.10545	-18.0835
2	1	2	1	-5.15357	-18.1051
3	1	3	1	-5.20143	-18.0943
4	2	1	1	-5.00840	-18.1051
5	2	2	1	-5.29636	-18.0835
6	2	3	1	-5.43683	-18.0727
7	3	1	1	-3.97314	-18.0943
8	3	2	1	-4.08240	-18.0943
9	3	3	1	-4.24375	-18.0835
10	1	1	2	-4.13652	-18.2869
11	1	2	2	-4.24375	-18.2869
12	1	3	2	-4.60898	-18.2869
13	2	1	2	-4.45433	-18.2869
14	2	2	2	-5.20143	-18.3080
15	2	3	2	-5.24902	-18.3080
16	3	1	2	-3.97314	-18.2974
17	3	2	2	-4.24375	-18.3080
18	3	3	2	-4.60898	-18.2974

**Table 6** Roughness response for each level of the process parameters of Al 1014 12mm thickness

Levels	(A) Point & Helix angle	(B) Spindle Speed	(C) Feed rate
1	-4.833	-4.742	-4.442
2	-4.524	-5.108	-4.704
3		-4.188	-4.891
Delta $\Delta_{\max-\min}$	0.309	0.920	0.450
Rank	3	1	2

Overall mean = -4.679

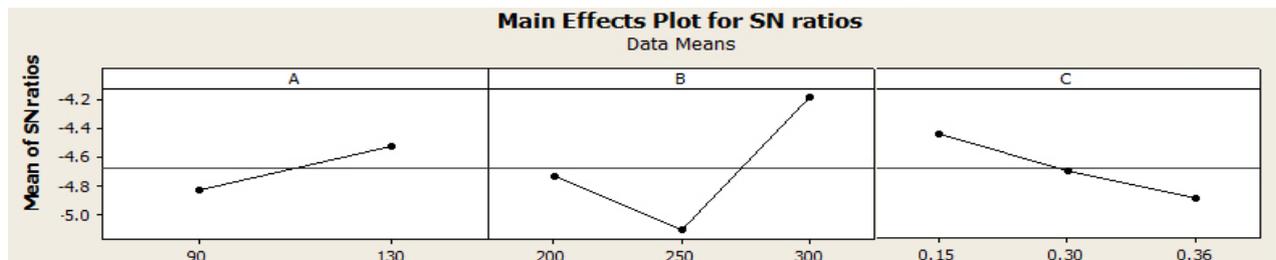
**Table 7** Analysis of variance (ANOVA) results for the Roughness for the drilling of Al 2014 12mm thickness

Source of variation	DOF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage (%)
A	1	0.4298	0.42980	5.16	0.042	9.31%
B	2	2.5756	1.28782	15.46	0.000	55.78%
C	2	0.6120	0.30602	3.67	0.057	13.26%
Error	12	0.9996	0.08330			21.65%
Total	17	4.6171				100%

**Table 8** Response for Roughness of Al 2014 12mm thickness

Level	A	B	C
1	1.748	1.728	1.670
2	1.686	1.802	1.722
3		1.620	1.758
Delta $\Delta_{\max-\min}$	0.062	0.182	0.088
Rank	3	1	2

Overall mean = 1.72



**Graph 1:** Plots of main effects for means, S/N ratio, and interaction data means of Roughness

**Table 9** Optimal level values for Roughness of Al 2014 12mm thickness from graph 1.

Process parameters	Levels	Roughness response value	S/N response value
A	2	1.686	-4.524
B	3	1.620	-4.188
C	1	1.670	-4.442

**Table 10** Confirmation experiment for Roughness of Al 2014 12mm thickness

	Optimal machining parameters	
	Prediction	Confirmation experiment
Level	A <sub>2</sub> B <sub>3</sub> C <sub>1</sub>	A <sub>2</sub> B <sub>3</sub> C <sub>1</sub>
Roughness (μm)	1.58	1.61
S/N ratio for Roughness	-3.97	-4.14

**Table 11** Hole Diameter response for each level of the process parameters of Al 2014 12mm thickness

Levels	(A) Point & Helix angle	(B) Spindle Speed	(C) Feed rate
1	-18.09	-18.19	-18.19
2	-18.30	-18.19	-18.20
3		-18.20	-18.19
Delta	0.21	0.01	0.01

$\Delta_{\max-\min}$			
Rank	1	3	2

Overall mean = -18.195

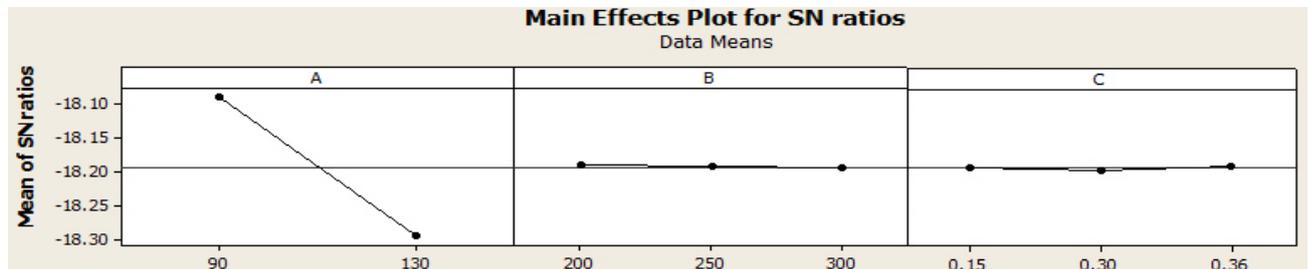
**Table 12** Analysis of variance (ANOVA) results for the hole Diameter for the drilling of Al 2014 12mm thickness

Source of Variation	DOF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage (%)
A	1	0.190145	0.190145	1568.05	0.000	99.11%
B	2	0.000085	0.000043	0.35	0.711	0.04%
C	2	0.000166	0.000083	0.68	0.523	0.09%
Error	12	0.001455	0.000121			0.76%
Total	17	0.191851				100%

**Table 13** Response for Hole Diameter of Al 2014 12mm thickness

Level	A	B	C
1	8.027	8.120	8.122
2	8.219	8.123	8.127
3		8.125	8.120
Delta $\Delta_{\max-\min}$	0.192	0.005	0.007
Rank	1	3	2

Overall mean = 8.123



**Graph 2:** Plots of main effects for means, S/N ratios, and interaction data means for of Hole diameter

**Table 14** Optimal level values for Hole Diameter of Al 2014 12mm thickness from graph 2

Process parameters	Levels	Hole Diameter response value	S/N response value
A	1	8.027	-18.09
B	1	8.120	-18.19
C	3	8.120	-18.19

**Table 15** Confirmation experiment for Hole Diameter of Al 2014 12mm thickness

	Optimal machining parameters	
	Prediction	Confirmation experiment
Level	A <sub>1</sub> B <sub>1</sub> C <sub>3</sub>	A <sub>1</sub> B <sub>1</sub> C <sub>3</sub>
Hole Diameter (μm)	8.03	8.021
S/N ratios for Hole Diameter	-18.09	-18.08

## VI. CONCLUSIONS

In this study, drilling of Al2014 alloy is carried out with the input drilling parameters considered as spindle speed, point angle and feed rate, and the response obtained are hole diameter and hole surface roughness at the entry and exit of the hole. The drilling parameters are optimized with respect to multiple performances in order to achieve a good quality of holes in drilling of Al 2014 alloy. Optimization of the parameters was carried out using Taguchi method

It was identified that a spindle speed of 300 rpm, point angle & Helix angle of 130°/20° and a feed rate of 0.15 mm/rev is the optimal combination of drilling parameters that produced a high value of s/n ratios of Hole roughness. And also identified that a spindle speed of 200 rpm, point angle & Helix angle of 90°/15° and a feed rate of 0.36 mm/rev is the optimal combination of drilling parameters that produced a high value of s/n ratios of Hole Diameter.

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