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INFLUENCE OF THE CUTTING PARAMETERS ON THE HOLE DIAMETER ACCURACY AND THE THRUST FORCE IN DRILLING OF ALUMINIUM ALLOYS

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Abstract: In this paper, the effect of the mechanical properties of aluminium alloys, cutting speed, feed rate and the point angle on diametric error and thrust force were investigated, using Taguchi method. Al-6061, Al-6351 and Al-7075 were selected as the work piece materials for experiments. The analysis of variance and signal-to-noise ratio were employed to analyze the effect of drilling parameters. The results of statistical analysis indicated that feed rate and cutting speed minimize significantly both the diametral error and the thrust force.

Keywords: Drilling, Diametral Error, Thrust Force, Al-6061, Al-6351, Al-7075 S/N Ratio, and ANOVA.

I. INTRODUCTION

Now a day's Drilling is one of the most important material removal processes that have been widely used in the aerospace, aircraft and automotive industries. Although modern metal-cutting methods, including electron-beam machining, ultrasonic machining, electrolytic machining and abrasive jet machining, have improved in the manufacturing industry, conventional drilling still remains one of the most common machining processes. Aluminium is used in many industrial areas to make different products and it is significant for the world economy. Structural components made from aluminium and aluminium alloys are vital in the aerospace industry and very important in other areas of transportation and building in which durability, strength and light weight are expected.

In several studies Diametral error and thrust force were investigated through examined the effect of the machining parameters on the thrust force and diameter deviations for different point angle drill bits. The results show that, small constant feed rate, low cutting speeds are appropriate for the dry machining of AL-6061. [6] Presented an application of Taguchi and response surface methodologies for minimizing the Diametral error and thrust force in drilling Al-7075. The optimization results showed that the combination of low cutting speed, low feed rate and high point angle is necessary to minimize both diametral error and the thrust force. [3] Investigated the role of different coatings, point angle and cutting parameters on the hole quality in the drilling of AL-6061 alloy and concluded that the cutting parameters have different effects on hole quality. They have obtained effective results using a low cutting speed and feed rate. By using several materials that were drilled by several cutting conditions, velocity and feed rates indicated that diametral errors were highly dependent on the material properties, the drill geometry and the cutting condition. [9] Used simulation tools and analysis of variance to identify the influence of process parameter on the hole diameter and concluded that feed rate, chisel-edge-to-drill diameter ratio, yield strength and point angle are significant for the hole diameter. [10] Carried out an experimental investigation of the role of various shapes of drills and materials (HSS Tool, Al-6061, Al-6351 and Al-7075) on the hole diameter in drilling. Their experimental results showed that the hole diameter from ductile materials is larger than from brittle materials. [11] Investigated the influence of the cutting parameters and the mechanical properties of a work piece on the hole diameter accuracy in a dry drilling process. His experimental results showed that the machining parameters and the mechanical properties of a work piece effect the hole diameter.

In this paper, a statistical analysis of the experimental data of the cutting parameters and the mechanical properties of aluminium alloys on the diametral error and the thrust force of the drilled hole in the dry drilling of Al-6061, Al-6351 and Al-7075 is investigated and analyzed with the Taguchi method.

II. MATERIALS, CUTTING CONDITIONS AND EXPERIMENTAL DESIGN

Diametral error and the thrust forces of the drilled hole were determined by cutting condition. The drilling experiments were conducted in dry cutting conditions on a drilling machine. In this study, Al-6061, Al-6351 and Al-7075 were chosen as the work materials with the specimen dimensions 120 mm × 100 mm × 20 mm. The mechanical properties of the three aluminium alloys are presented in Table I. Uncoated, conventional, high-speed-steel twist drills with diameter of 10 mm with different point angles 90° and 118° are used for drilling experiment. Diametral error and the thrust force of each drilled hole were measured by means of a digital vernier callipers and a dynamometer. Diametral error and the thrust force of the machined hole specimen was measured from two different points (90° and 180°) for both, Diametral error and the thrust force. The drilling experiments were planned using Taguchi's orthogonal array. Three experimental parameters were the cutting speed; feed rate and point angle were selected for the present investigation. Four levels of each control factor were taken into account. Taguchi's orthogonal array of L_{16} was chosen for the experimental plan. The considered experimental factors and their levels are listed in Table II.

Table I: Mechanical Properties of Al-6061, Al-6351 and Al-7075 Materials

Material	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Hardness (HRB)
Al-6061	310	276	17	95
Al-6351	250	150	20	95
Al-7075	228	103	16	60

The parameters and their levels are shown in table II.

Table II. Process Parameters and their Levels

Parameter	Level 1	Level 2	Level 3	Level 4
Spindle Speed (Rpm)	90	200	250	400
Feed Rate(mm/rev)	0.15	0.2	0.3	0.36
Point Angle	90˚	118˚	--	--

III. EXPERIMENTAL RESULTS AND ANALYSIS

The Taguchi method is very popular for solving optimization problems in the field of manufacturing engineering [13]. In this method, the term "signal" (S) represents the desired value and the "noise" (N) represents the undesired value. The objective of using the *S/N* ratio is a measure of the performance to develop products and processes that are insensitive to noise factors. The *S/N* ratio indicates the degree of predictable performance of a product or process in presence of noise factors. The process parameter settings with the highest *S/N* ratio always yield the optimum quality with minimum variance. The difference between the functional value and the objective value is emphasized and identified as the loss function. The loss function is derived as Eq. (1)

$$L(y) = \frac{L''(m)(y-m)^2}{2!} = k(y-m)^2 = k(MSD) \text{ ------------ } (1)$$

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Vol. 2, Issue 11, November 2013

Table III: Experimental Layout Using L_{16} Orthogonal Array and Experimental Values

Sl. No	Speed (Rpm)	Feed (mm/rev)	Point angle (Deg)	Diametral Error(mm) Al - 6061	Thrust force(Nm) Al - 6061	Diametral Error(mm) Al - 6351	Thrust force(Nm) Al - 6351	Diametral Error(mm) Al - 7075	Thrust force(Nm) Al -7075
1	90	0.15	90	0.23	696	0	657	0.15	755
2	90	0.2	90	0.02	853	0.03	892	0.09	853
3	90	0.3	118	0.02	1177	0.34	951	0.13	1570
4	90	0.36	118	0.01	1608	0.22	1030	0.21	1618
5	200	0.15	90	0.03	696	0.09	627	0.25	676
6	200	0.2	90	0.13	775	0.03	785	0.32	902
7	200	0.3	118	0.03	1157	0.37	873	0.42	1667
8	200	0.36	118	0.06	1236	0.09	1030	0.26	1716
9	250	0.15	118	0.04	520	0	657	0.06	1030
10	250	0.2	118	0.06	716	0.1	686	0.02	1275
11	250	0.3	90	0.01	686	0.09	1108	0.1	1128
12	250	0.36	90	0.17	1059	0.1	1206	0.13	1137
13	400	0.15	118	0.18	559	0.07	627	0	1226
14	400	0.2	118	0.01	696	0.1	853	0	1363
15	400	0.3	90	0.03	1000	0.01	1255	0.08	706
16	400	0.36	90	0.05	853	0.1	1255	0.09	1530

Table IV: Response Table for Diametral Error and Thrust Force

Factors	Mean S/N ratio for DE				Mean S/N Ratio for TF			
	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
Al-6061								
Cutting speed	30.18	25.77	26.95	27.84	-60.25	-59.44	-57.16	-57.60
Feed rate	21.52	29.03	33.72	26.46	-55.74	-57.59	-59.85	-61.27
Point angle	25.85	29.52	-	-	-58.24	-58.98	-	-
Al-6351								
Cutting speed	17.66	20.23	20.31	25.77	-58.79	-58.23	-58.90	-59.63
Feed rate	22.01	25.23	19.73	18.52	-56.15	-58.06	-60.31	-61.03
Point angle	26.11	16.45	-	-	-59.46	-58.32	-	-
Al-7075								
Cutting speed	17.17	10.29	24.03	21.43	-61.07	-61.21	-61.13	-61.28
Feed rate	17.65	21.60	16.80	15.97	-59.05	-60.63	-61.59	-63.42
Point angle	17.49	18.15	-	-	-59.34	-63.01	-	-

where $L(y)$ is the loss function, y is the value of the quality characteristic, m is the target value of y, k is the commensurately constant, which depends on financial criticality of y, and MSD is the mean square deviation. Eq. (1) can be expressed by the signal-to-noise ratio (ç) and can be rewritten as:

$$\eta = -10 \lg_{10} (MSD) \text{ ---------------- } (2)$$

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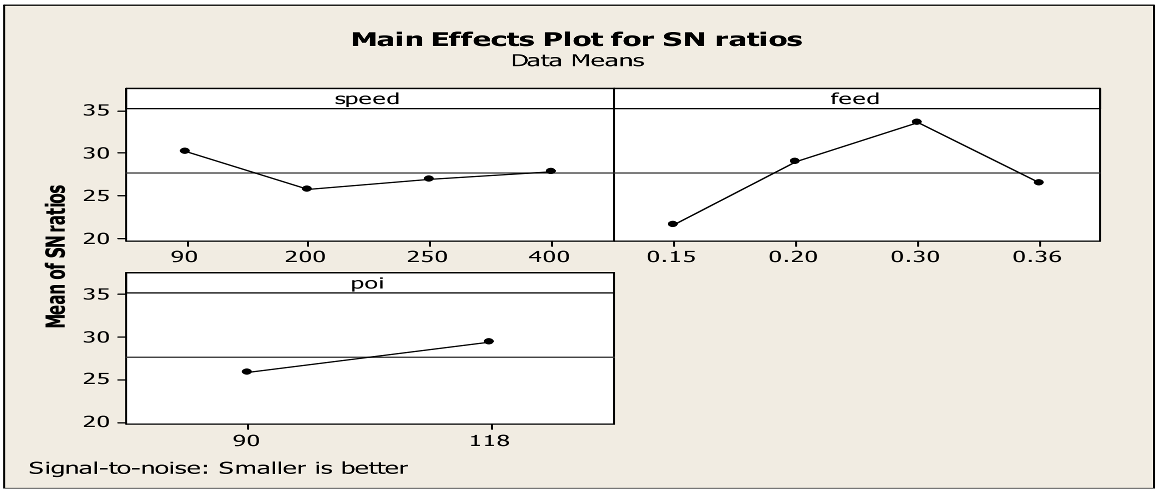
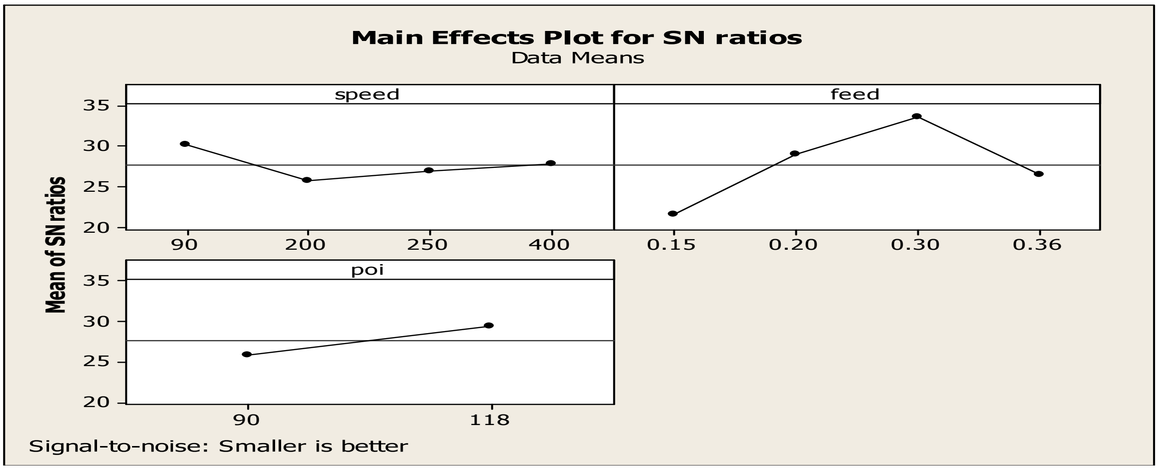
The value of the loss function is further transformed into a signal-to-noise (*S/N*) ratio. In the present investigation, the objective is to minimize the diametral error and the thrust force. Therefore, "smaller is better" as a quality characteristic is selected, which is a logarithmic function given as: Eq. (2)

$$S/N\ (\eta) = -10\ \lg_{10}\left(\frac{1}{r}\sum_{i=1}^{r} R_i^2\right) \quad i=1, 2, 3, \ldots..r \quad \text{-------------} \ (3)$$

Where R_i is the value of the Diametral error or the thrust force for the i^{th} trial in r number of measurements [14]. The experimental values obtained from the experiments related to diametral error and the thrust forces are illustrated in Table III. The *S/N* ratios for the diametral error and the thrust force were calculated using the output parameter values given in Table III. The *S/N* ratio for each parameter level was calculated by averaging the *S/N* ratios obtained when the parameter maintained at that level. Table IV shows that the obtained *S/N* ratios for different parameter levels.



(a) Diametral Error: AL-6061



(b) Diametral Error: AL-6351

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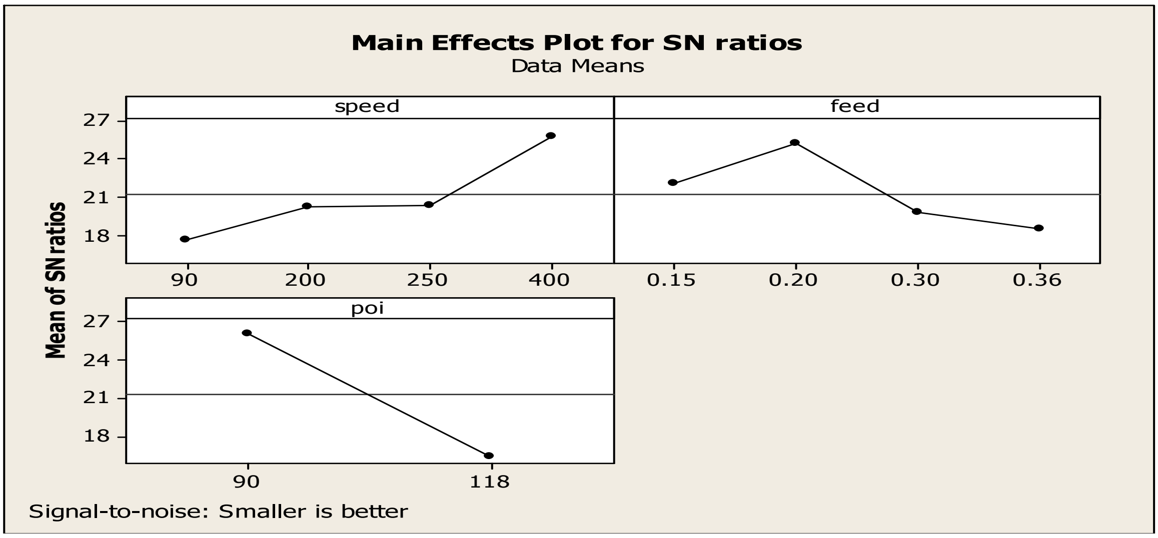
Vol. 2, Issue 11, November 2013



(c) Diametral Error: AL-6061

Figure 1: Effect of cutting parameters on the diametral error: (a) Al-6061 (b) Al-6351 and (c) Al-7075

Table V: The result of ANOVA for Diametral Error

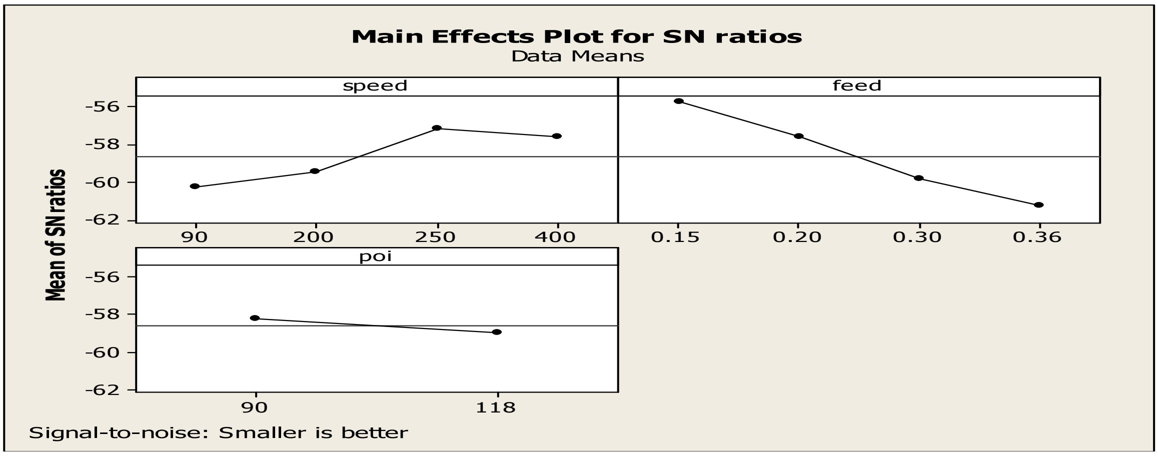
Factors	Dof	SS	V	PI%
AL-6061				
Cutting speed	9	122816.6	631.548	60.82
Feed	9	0.0624	0	0
Point angle	9	1698.66	0	0.84
Error	18	77420.65	12902.564	38.34
Total	45	201935.97		100.00
AL-6351				
Cutting speed	8	155783.33	7825.426	77.15
Feed	8	0.0493	0	0
Point angle	8	1437.33	0	0.71
Error	21	44715.26	6387.30	22.14
Total	45	201935.96		100.00
AL-7075				
Cutting speed	12	137950	0	68.31
Feed	12	0.0924	0.002	0
Point angle	12	2744	80.41	1.37
Error	9	61242.1	20283	30.32
Total	45	201936.19		100.00

Table VI: The result of ANOVA for Thrust force

Factors	Dof	SS	V	PI%
AL-6061				
Cutting speed	12	101350	0	50.19
Feed	12	0.0938	0.02	0
Point angle	12	2613.33	36.046	1.29
Error	9	97972.67	32657.55	48.52
Total	45	201936.09		100.00

Factors	Dof	SS	V	PI%
		AL-6351		
Cutting speed	11	159950	3662.9	79.20
Feed	11	0.1065	0.007	0
Point angle	11	2352	13.517	1.17
Error	12	39634	9908.5	19.63
Total	45	201936.1		100.00
		AL-7075		
Cutting speed	15	198800	13253.3	98.45
Feed	15	0.1083	0.007	0
Point angle	15	3136	209.061	1.55
Error	0	0	0	0
Total	45	201936.1		100.00

The response graphs for the *S/N* ratios of the diametral error and thrust force are shown in Figures 1 and figure 2. It is observed from the *S/N* response graph that the optimum parameter level combinations for the minimum values of Al-6061, Al-6351 and Al-7075 are A1B1C1, for both diametral error and thrust force. As shown in Table IV and Figure 1, the feed rate is the dominant parameter on the diametral error followed by the cutting speed. Although a lower Diametral error is always preferred. In the present investigation, when cutting speed 90 rpm, feed rate 0.15 mm/r and point angle 90^0 are used, the diametral error is minimized. The Diametral error increases as the feed rate, the cutting speed and the point angle increase. As shown in Table IV, cutting speed is the dominant parameter on thrust force, followed by the point angle. The feed rate has a lower effect on thrust force. In the present investigation, when applied by cutting speed 90 rpm, feed rate 0.15 mm/r and point angle 90^0, the surface roughness is minimized. The thrust force of the drilled surface increases with increase of feed rate, cutting speed and point angle. The results of the analysis of variance (ANOVA) for the diametral error are presented in Table V. From the analysis, for all three aluminium alloys the feed rate is a highly significant factor and plays a major role in affecting the diametral error. It can be observed from Table V that cutting speed also affects the diametral error. The effect of the point angle does not make any impact on the responses, except for Al-7050. Percent (%) is described as the significance rate of the process parameters on the diametral error. It can be observed from the ANOVA Table that the cutting speed, feed rate and point angle are effect on the Diametral error 60.82 %, 0 % and 0.84 %; 77.15 %, 0 % and 0.71 %; 68.3 %, 0 % and 1.37 % in drilling of Al-6061, Al-6351 and Al-7075, respectively.



(a) Thrust Force: AL-6061

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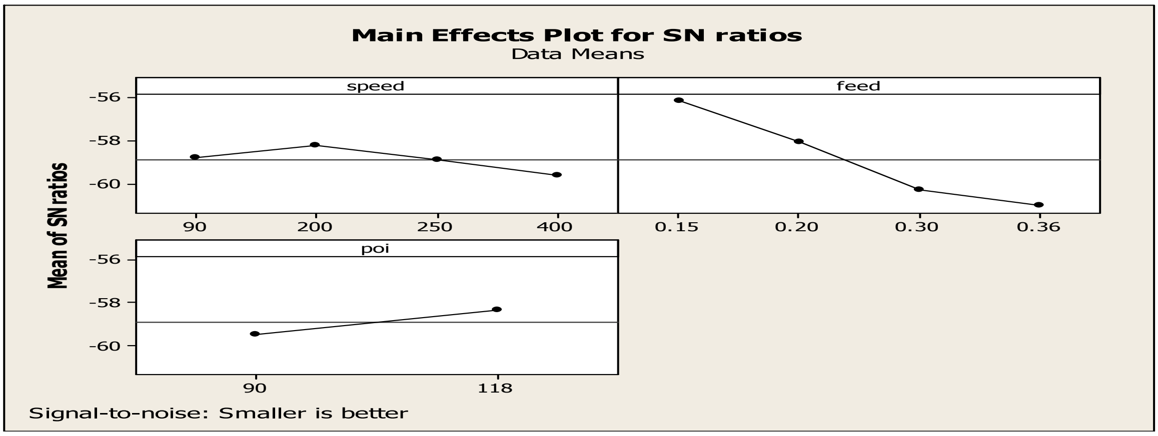
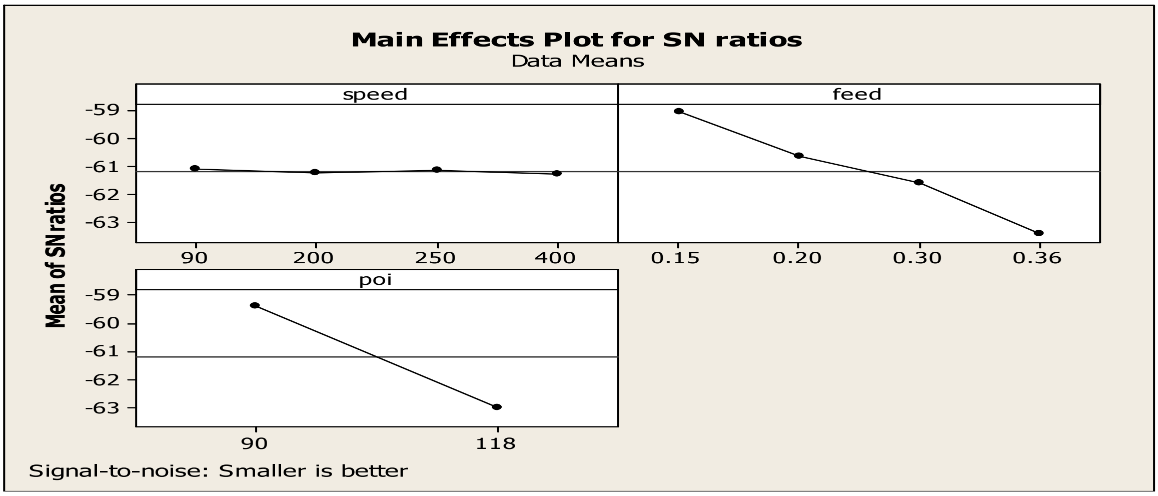


(b) Thrust Force: AL-6351



(c) Thrust force: Al-7075

Fig 3: Effect of Cutting Parameter on the Thrust Force: (a) AL-6061 (b) AL-6351 (c) AL-7075

A series of experiment were conducted on three types of aluminium. The properties of the work piece material have a significant influence on the diametral error. The burr formation process is heavily dependent on the yield strength, ultimate strength [9] and ductility [4]. Also considering the ductility of materials represented as elongations in Table I for the alloys Al-6061, Al-6351 and Al-7075. The higher value of elongation represents better ductility of the material. Al-6061 shows more ductility than the Al-6351 and Al-7075 alloys. The elongation percentage of work pieces used in the experiments affects the diametral error and thrust force. The amount of diametral error which is drilled in Al-6061 alloy material is greater for Al-6351 and Al-7075, because Al-6061 is more ductile than Al-6351 and Al-7075. Also the difference of diametral error in Al-6351 and Al-7075 is not large; Al-6351 produces the smaller diametral error. As a result, much more Diametral error occurs in ductile materials. This tendency was also mentioned by various other researchers [4], [8–10]. The final burr geometry determined by the amount of plastic deformation is determined by the ductility of the material represented as elongations.

Al-6351 alloy machined surface, shows a lower value of the diametral error compared to Al-6061 and Al-7075 alloys. Higher thrust force values of Al-6061 alloy can be explained by the highly ductile nature of the alloy, which increases the tendency to form a built-up edge (BUE). Relatively higher work piece ductility increases the BUE formation tendency [16]. The presence of the BUE in the drilling process causes an increase in the tool wear and a rougher surface finish.

IV. CONCLUSIONS

Based on the *S/N* ratios and the ANOVA results of diametral error and thrust force of Al-6061, Al-6351 and Al-7075 specimens, the following conclusions have been drawn:

- It is concluded that cutting speed was the most influential controllable factor among input parameters which affect the hole diameter. The feed rate was the second factor at hole diameter accuracy. The point angle has the lowest effect on hole diameter.
- The Best parametric combination of the three control factors is minimization of both the Diametral error and thrust force; cutting speed i.e. at level-1(90 rpm), feed rate i.e. at level-1 (0.15 mm/rev) and point angle i.e. at level-1 (90^0).
- Due to the ductility of the material, the amount of diametral error in Al-6061 alloy material is much less than in Al-6351 and Al-7075.
- The thrust force obtained by Al-6061 is best than by Al-7075 and Al-6351 alloys.

Through the utilizing optimal conditions obtained by S/N ratio, the Diametral error and thrust force is minimized which contributes the reduction of the overall manufacturing cost by reducing the number of experiments.

SCOPE FOR FUTURE WORK

The above work can also be extended through as follows

- Influence of Helix angle, number of flutes on hole quality.
- Wider range of process parameters for studying the effects of them on hole quality.

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BIOGRAPHY

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C. Thirupathaiah was born in kadapa on 01/07/1976. He is doing his M.Tech in mechanical engineering in the area of Industrial Engineering from S. V. University, Tirupati in the year 2013. B. Tech in Mechanical Engineering from KSRM engineering college affiliated to S. V. University, in the year 1998.