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To Study on Burr Development during Drilling Operation of Aluminium Alloy (Al6061)

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ABSTRACT

Drilling operation is one of the finishing operation in the production cycle, removal of burrs during drilling process is a time consuming and non-value added process to the manufacturing sector. In the present work, minimization of burr size and hole quality is considered during drilling of aluminium alloy series of 6061. experiments are conducted based on Grey based Taguchi approach by chosen L27 orthogonal array corresponding to five input parameters such as spindle speed (rpm), feed rate (mm/min), drill diameter (mm), point angle (degrees) and clearance angle (degrees) with three levels and measured six responses viz., burr height (mm), burr thickness (mm), roundness error (mm), thrust force (N), torque (N-mm) and surface roughness (μm) using precise measuring equipment. Based on main effect plots and interaction plots of data means of responses from results of ANOVA, confirmation tests are conducted by choosing most significant parameters. Feed rate, point and clearance angles are the most influential factors on burr size and also experimental results that the lower the thrust force yields to decrease the burr height.

Keywords : Drilling, Burr, Aluminium alloy, Grey based Taguchi approach, ANOVA

I. INTRODUCTION

Precision manufacturing has gained much prominence in manufacturing industries in the recent past. The best product dimensions and minimization of time and cost of production has become a measure of concern. Most of the manufacturing processes such as milling, drilling and boring etc. for product design are to achieve the qualitative products. Drilling process takes care about 35% of all machining processes [1-4] and influences the acceptability of the products as the drilling process is at the most final processing stage in the production line. The burr, which is a plastically deformed material, engendered during drilling is a preventable output and often lowers the surface quality, diminishes the product life and acceptability of the product. Total elimination of burrs during drilling process is a trivial task, however, with proper selection of process parameters, it can be curtailed. Selection of process parameters according to workpiece material and hole quality requirements, is critical for the minimization or prevention of burr formation. However, analytical models developed so far for the interaction between process conditions; material properties and burr formation are limited. Therefore, the burr, an unintended outcome of machining processes, has been a widely recognized problem in the industry. Burrs ruins the integrity of design of the part. All these side effects causes unnecessary cost to the industry in various forms such as additional machining, compensation, service, redesign and collateral damage on the company reputation. Therefore, in most cases, it is a must either to remove or to secure the burr in order to prevent from being detached as of the part. Traditionally, burr problems had been considered unavoidable so that most efforts made on removal of the burr as a post process. Nowadays, a trend of manufacturing is an integration of the whole production flow from design to end product. Manufacturing problem issues are handled in various stages, even from design stage. The methods of describing the burr are gaining much attention in recent years for the systematic approach to resolve the burr problem at various manufacturing stages. The present work aims at developing a mathematical model for thrust force and burr formation in drilling operation. Thereby validating these models, experiments are conducted by varying different process parameters. The proposed work is to minimize the burr formation and to evaluate the influence of process parameters in drilling are prescribed to achieve good quality to the product and minimize the deburring cost.

Burr Formation: While drilling, two burrs are formed: a small entrance burr and a much bigger exit burr. The process of drilling exit burr formation can be divided into three different stages as shown in Fig.1.

1. When the drill approaches the exit side of the workpiece, the chisel edge of the drill produces the plastic deformation of the work beneath material.

2. Then a bulge develops on the bottom surface of the workpiece. The remaining material in front of the corners of the tool is still strong enough to withstand the thrust force of the drilling operation. Thus, no plastic deformation occurs in this region and the normal cutting process continues.

3. As the material beneath the chisel edge reaches its maximum elongation, it starts to tear and finally the drill breaks through and the remaining material is bent out and becomes the burr.

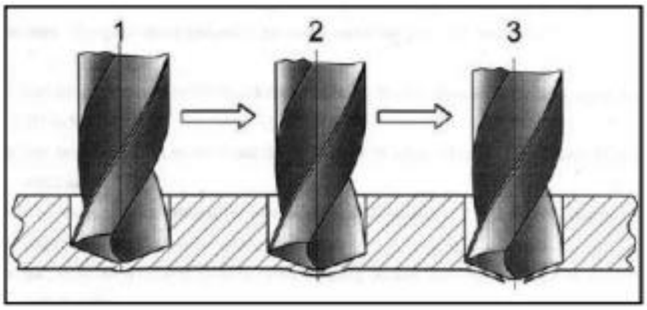

Fig.1: Burr formations in three different stages [2]

Surface Roughness: The reliability of the process in achieving the required surface finish is important as otherwise it adds to the cost of manufacture through part rejection and rework. One of the principal design considerations for extremely stressed components will be the surface condition produced during manufacturing. With regard to the quality characteristics of drilled parts, some of the problems encountered include hole surface roughness. Many factors effect hole diameter and surface quality, which can be divided into controllable and non-controllable parameters for better hole diameter accuracy and surface roughness.

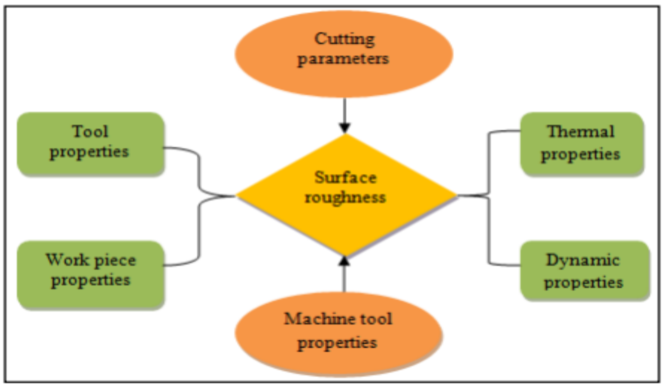

Fig.2: Six major categories that effect on surface roughness

There are three essential parameters in surface roughness, arithmetical mean deviation of the profile (R_a), maximum height of the profile (R_{max}) and height of the profile irregularities in ten points (R_z). In drilling, surface roughness mainly dependent on the feed rate, also influenced by the point angle of the drill and wear status of the outer corner of the two cutting edges. It has been found that drill material has the most important influence on surface finish of the work material.

As manufacturing processes became advanced, precision components require more attention to both the generation of surfaces and dimensions with tight tolerances. High quality products should be precisely manufactured according to the design specifications with minimal costs. Drilling is one of the most common and complex operations among many kinds of machining processes, used in a variety of manufacturing industries including aerospace and automotive sectors. An unwanted projection of material formed during the drilling process, termed as burr as a part size errors.

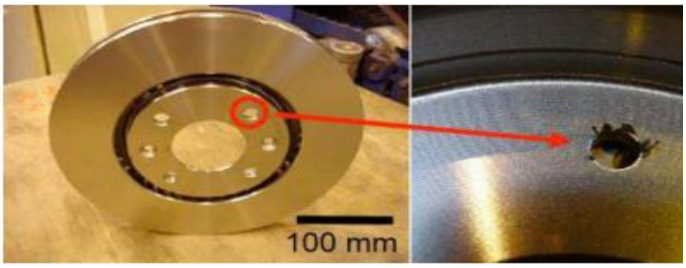

Fig.3: Micro image of burr formation on Flange

Burr formation in drilling is influenced by many factors, among those workpiece material like shear strength and hardness on the size of exit burrs while drilling of steels, drill geometry and process conditions are known to be more influential by Sofronas et al. [1,2] have focused on their effects on burr formation. Stein and dornfeld et al. [3] determined the sensitivity of feed, speed, drill wear and exit surface geometry in drilling of 0.91 mm diameter through holes in stainless steel material (304L). A quantitative burr formation model proposed by Ko and dornfeld et al. [4] for ductile materials during orthogonal cutting, reveals that the influence of machining parameters on burr size was evaluated with machining tests performed in a scanning electron microscope (SEM). Sugawara and Inagaki et al. [5, 6] investigated to know the effects of drill edge shapes and working conditions on burr formation, conducted a model experiment by selecting ten drill bits of each different diameter. Takazawa et al. [7] has explored several techniques that can be used for observing the effect of part material on burr formation in drilling. It was claimed that the drilling burrs produced by a drill with a nick on the cutting lips were smaller than the burrs produced by conventional drills. Kim et al. [8] carried out preliminary experiment to investigate the burr formation on drilling of Ti-6A1-4V titanium alloy, which is most widely used in aircraft industry because of its high specific strength. Shefelbine and Dornfeld et al. [9] investigated the effect of dry machining on burr size and reported that dry machining without coolant could be advantageous because of decreased costs associated with the use of coolant and a decrease in possible negative effects on worker health and the environment. Pande and Relekar et al. [10] observed that the burr formation tendency especially with reference to burr height and thickness at entry and exit of the holes during drilling by changing the drill diameter, feed rate, length of hole to diameter ratio

(L/D ratio) and BHN of the work piece material. Lin and Shyu et al. [11] adapted variable feed machining process for improving cutting tool life and exit burr height for hard and difficult to machine materials. Wada and Yoshida et al. [12] emphasized on burr less drilling of various metals. The roundness of the drill's corner reduced the burr to a very small size. Takeyama et al. [13, 14] also reported that the burr around the hole exit can be minimized by applying ultrasonic vibration in the direction of drill feed. Simon et al. [15] highlighted the use of ultrasonic assistance, where the high frequency and low-amplitude ultrasonic vibrations are added in the feed direction for the reduction of burr size in drilling of aluminium work pieces. Nripen Mondal et al. [16] reported on minimization of burr height under different machining conditions for a low alloy steel specimens. Sanjib Kundua et al. [17] and Das, R, Barik, T et al. [18] also provided back up support on aluminium alloy to minimize burr height using orthogonal array design of Taguchi is applied to minimize burr height of aluminium alloy flats by optimizing three drilling process parameters viz. cutting velocity, feed and machining environment. A. Saravanakumar et al. [19] analyzed the burr height at exit of the holes during drilling of hybrid aluminium matrix composite using TiN coated solid carbide twist drills. Rajiv Chaudhary et al. [20], reviewed on experimental investigations in drilling using Taguchi techniques Ugur koklu et al. [21] investigated, the effect of mechanical properties of aluminum alloys, cutting speed, feed rate and drill diameter on burr height and surface roughness of drilling holes, using the Taguchi method. Shanti Parkash et al. [22] investigated experimentally by Taguchi method for minimizing the burr height in drilling of Al – Fly ash composite. Kilickap et al. [23] presented the use of Taguchi and RSM for minimizing the Burr height and surface roughness in drilling of Aluminium 7075 alloy under dry condition. Nouari et al. [24] experimentally tested the effect of the drilling parameters on the hole surface roughness and diameter deviations for different coated drills on aluminum alloys. Hari Singh et al. [25] conducted drilling experiments using L27 orthogonal array, to optimize the process parameters considering weighted output response characteristics using grey relational analysis. Tosun et al. [26] applied grey relational analysis to optimize the drilling process parameters for the surface roughness and burr height by considering various drilling parameters viz., feed rate, cutting speed, drill diameter and point angle. from the review of literature, it is observed that drilling of aluminium 6061 alloys are considered to minimize burr size by changing the feed rate, spindle speed and tool geometry under dry condition.

II. Methodology:

Material: Aircraft, automotive industries for structural and making components with reduction of weight purposes aluminium alloys are required and needs making numerous number of holes in drilling to assemble the components. So, day to day increase in demand of aluminium alloys in the areas of aircraft, automotive and marine industries, Al 6061 alloy chosen to conduct drilling experiments. Various applications of aluminium alloy are as shown in Fig.4 and compositions of various elements and properties of Al 6061 alloy depicted in Table 1 & 2

Fig. 4: Trend of aluminum components in cars in the last 50 years [9]

Table 1: Composition of aluminium alloy (Al 6061)

Composition	Si	Cu	Zn	Iron	Mn	Mg	Ti	Cr	Al
Wt%	0.63	0.196	0.191	0.466	0.179	0.932	0.038	0.028	Remaining

Table 2: Mechanical Properties of aluminium alloy (Al 6061)

Property	Al 6061
	Wt%
Brinell hardness (BHN)	81
Shear Strength (MPa)	207
Thermal conductivity (W/m-K)	167
Density (gm/cc)	2.7

Selection of input parameters: The presence of burrs on the edges of parts after machining may bring about a number of problems. In the first case, burrs are often quite sharp and can lead to injuries to the workers while assembling. Secondly, burrs which initially stick to a part can become loose during operation of a product in due course and cause functional damage. During the drilling process, burrs form on both the entry and exit surfaces as a result of plastic deformation of the workpiece material.

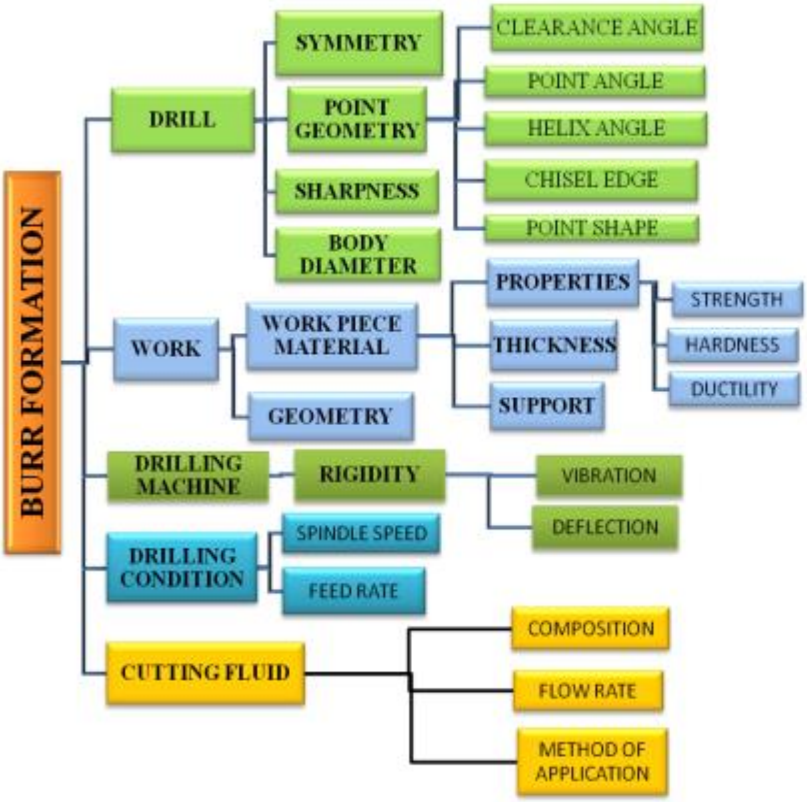

Fig. 5: Influenced parameters on burr formation in drilling

The process of selection of the drill bit, process parameters are based on the above mentioned criterion for drilling of aluminium alloy. The outputs to be recorded are the ones that can be influenced by the above selected parameters are mainly thrust force and torque generated during drilling, burr size (height and thickness), surface roughness and roundness error obtained due to the interaction of the drill bit with the workpiece.

Design of experiments based on Taguchi method: The selected input parameters and their levels as per Taguchi's design plan are depicted as in Table 3

Table 3: Drilling parameters and levels

Levels	Drilling Parameters				
	Spindle Speed (rpm)	Feed Rate (mm/min)	Drill Diameter (mm)	Point Angle (Degrees)	Clearance Angle (Degrees)
	A	B	C	D	E
1	465	18	8	100	4
2	695	20	10	110	6
3	795	26	12	118	8

In the present study, 300 mm × 50 mm × 10 mm plates of the selected work materials such as Al 6061 alloy is used for the drilling experiments. Plan of experiments based on Taguchi orthogonal array and output responses as shown in Table 4

Table 4: Plan of experiments and output responses while drilling of Al 6061 alloy

Exp. No.	A rpm	B mm/min	C Mm	D degree	E Degree	R_1 Mm	R_2 mm	R_3 mm	R_4 Mm	R_5 mm	R_6 mm
1	465	18	8	100	4	0.262	0.178	0.058	218.3	162.5	2.39
2	465	18	8	100	6	0.254	0.166	0.063	249.1	152.7	1.16
3	465	18	8	100	8	0.248	0.161	0.152	297.4	180.2	4.5
4	465	18	8	100	8	0.248	0.161	0.152	297.4	180.2	4.5
5	465	18	8	100	8	0.248	0.161	0.152	297.4	180.2	4.5
6	465	18	8	100	8	0.248	0.161	0.152	297.4	180.2	4.5
7	465	26	12	118	4	0.238	0.149	0.027	328.3	140.6	4.05
8	465	26	12	118	6	0.347	0.241	0.036	287.1	176.4	3.45
9	465	26	12	118	8	0.242	0.184	0.174	225.4	138.4	2.29
10	695	18	10	118	4	0.318	0.243	0.088	326.3	258.5	3.33
11	695	18	10	118	6	0.222	0.159	0.109	331.2	220.4	2.253
12	695	18	10	118	8	0.328	0.218	0.122	226.4	181.5	1.06
13	695	20	12	100	4	0.228	0.156	0.029	268.5	167.6	3.26
14	695	20	12	100	6	0.200	0.151	0.041	293.2	208.3	3.6
15	695	20	12	100	8	0.182	0.164	0.132	303.2	218.2	1.56
16	695	26	8	110	4	0.324	0.228	0.026	367.2	203.2	3.54
17	695	26	8	110	6	0.219	0.147	0.094	312.4	164.3	2.45
18	695	26	8	110	8	0.244	0.22	0.085	296.5	192.2	4.38
19	795	18	12	110	4	0.214	0.189	0.066	225.4	183.3	2.89
20	795	18	12	110	6	0.209	0.191	0.100	327.1	234.4	2.91
21	795	18	12	110	8	0.268	0.233	0.107	224.2	188.8	3.413

22	795	20	8	118	4	0.258	0.212	0.089	222.4	195.4	3.11
23	795	20	8	118	6	0.239	0.252	0.141	302.7	207.2	3.02
24	795	20	8	118	8	0.196	0.163	0.182	268.4	178.2	1.65
25	795	26	10	100	4	0.186	0.152	0.072	247.3	207.4	2.72
26	795	26	10	100	6	0.223	0.169	0.111	340.2	282.6	3.46
27	795	26	10	100	6	0.223	0.169	0.111	340.2	282.6	3.46

Experimental Setup: Experiment is performed on radial drilling machine to perceive the burr formation and its associated parameters. The dynamometer is fitted on the work table of the radial drilling machine to read the forces generated during the experiment. The burr height and burr thickness of the drilled holes, after completion of experiment, output parameters are measured using tool maker's microscope. After edge finishing of each hole, roundness error is measured equidistantly along the periphery of the holes using the coordinate measuring machine. The surface roughness of the drilled holes is measured using a surface roughness tester.

Fig.5: Experimental Setup

III. Results and Discussion

Main effects of output responses

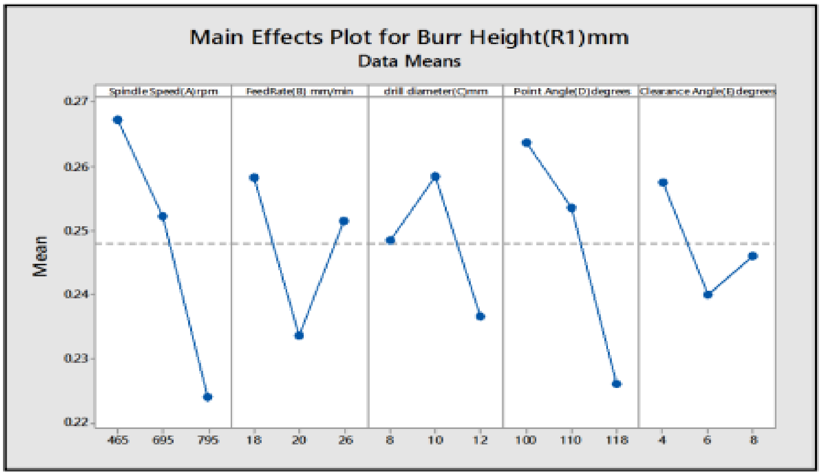

Fig.6: Main effects plot for data means of Burr Height (Al 6061)

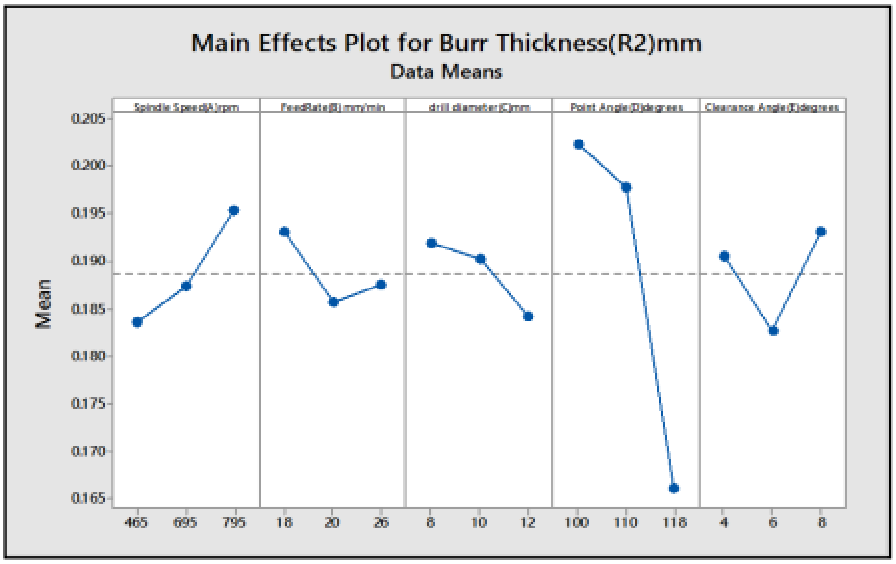

Fig.7: Main effects plot for data means of Burr Thickness (Al 6061)

From these plots, analysis of the setting of optimal process parameters to attain the multiple performance characteristics of outputs which are measured in the experimentation. The main effects plot of burr height shown in Fig.6 reveals that the setting of parameters $A_1B_1C_2D_1E_1$ indicates 465 rpm, 18 mm/min, 10 mm, 100^0 and 4^0 respectively are the optimal setting of input parameters for Al 6061 alloy. The main effects plot shown in Fig.7 for burr thickness obtained from Minitab@17 software reveals that the setting of input parameters are $A_3B_1C_1D_1E_3$ indicates 795 rpm, 18 mm/min, 8 mm, 100^0 and 8^0 respectively are the optimal combination of input parameters to attain the desired objective for Al 6061 alloy.

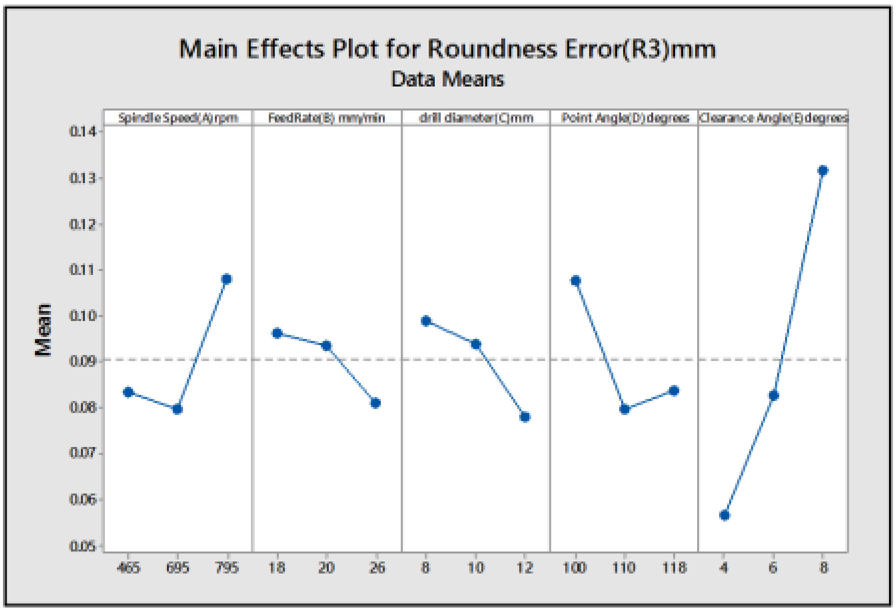

Fig.8: Main effects plot for data means of Roundness Error (Al 6061)

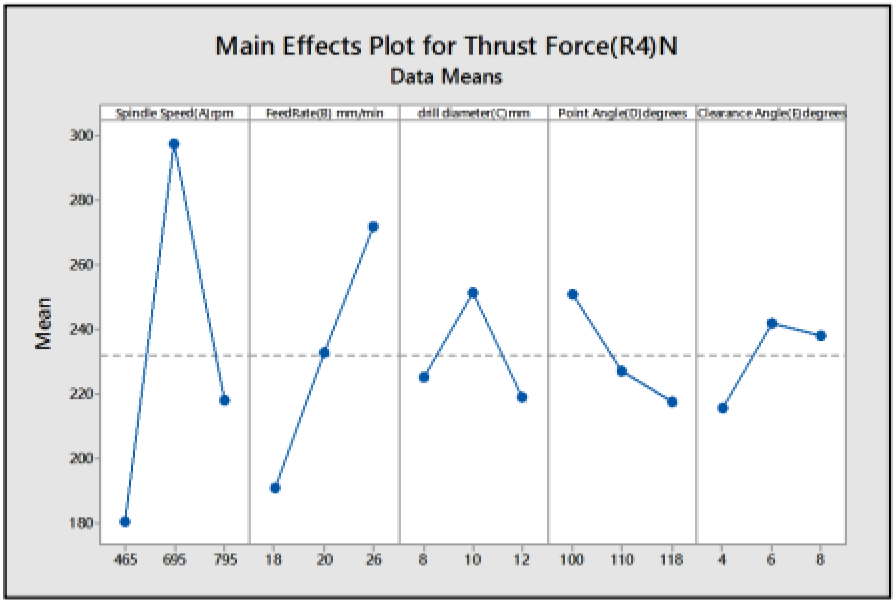

Fig.9: Main effects plot for data means of Thrust force (Al 6061)

The main effects plot shown in Fig.8 for roundness error is $A_3B_1C_1D_1E_3$ shows that 795 rpm, 18 mm/min, 8 mm, 100^0 and 8^0 with respect to inputs respectively are the optimal combination of input parameters to attain the desired objective for Al 6061 alloy. The main effects plot shown in Fig.9 for thrust force reveals that the setting of input parameters are $A_2B_3C_2D_1E_2$ indicates 695 rpm, 26 mm/min, 10 mm, 100^0 and 6^0 respectively are the optimal setting of parameters to attain the objective for Al 6061 alloy.

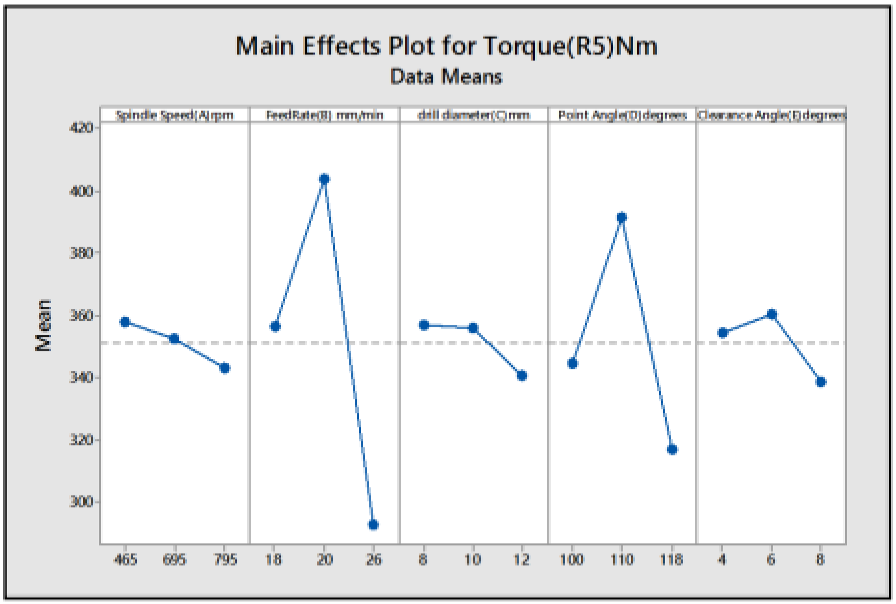

Fig.10: Main effects plot for data means of Torque (Al 6061)

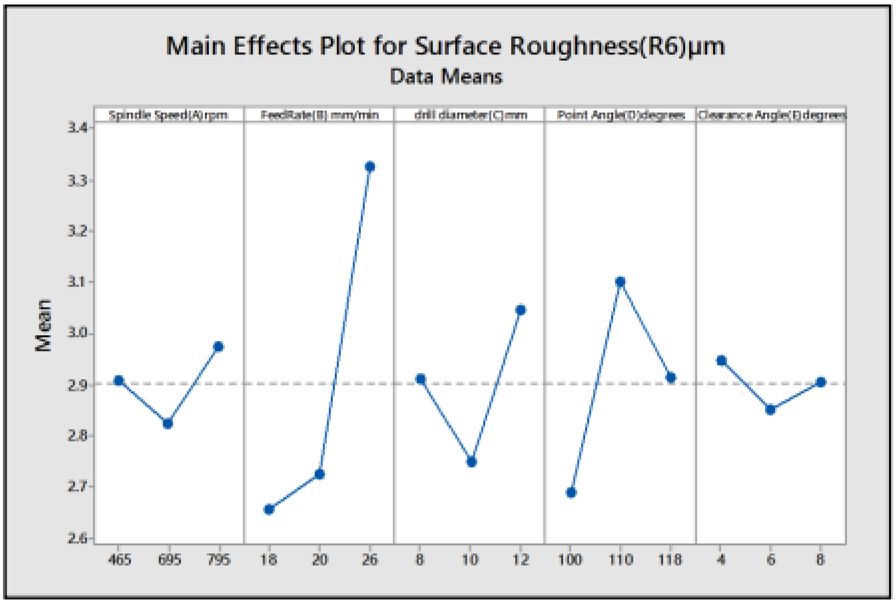

Fig.11: Main effects plot for data means of Surface Roughness (Al 6061)

The main effects plot shown in Fig.10 for torque reveals that the values of parameters are $A_1B_2C_2D_2E_2$ represent 465 rpm, 20 mm/min, 10 mm, 110^0 and 6^0 respectively are the optimal values of input parameters to meet the desired objective for Al 6061 alloy. The main effects plot shown in Fig.11 for surface roughness reveals that the setting of parameters are $A_3B_3C_3D_2E_1$ represent 795 rpm, 26 mm/min, 12 mm, 110^0 and 4^0 respectively are the optimal setting of input parameters to meet the desired objective for Al 6061 alloy.

Interaction plots for output responses: Interaction effects represent the combined effects of factors on the dependent measure. When an interaction effect is present, the impact of one factor depends on the level of the other factor.

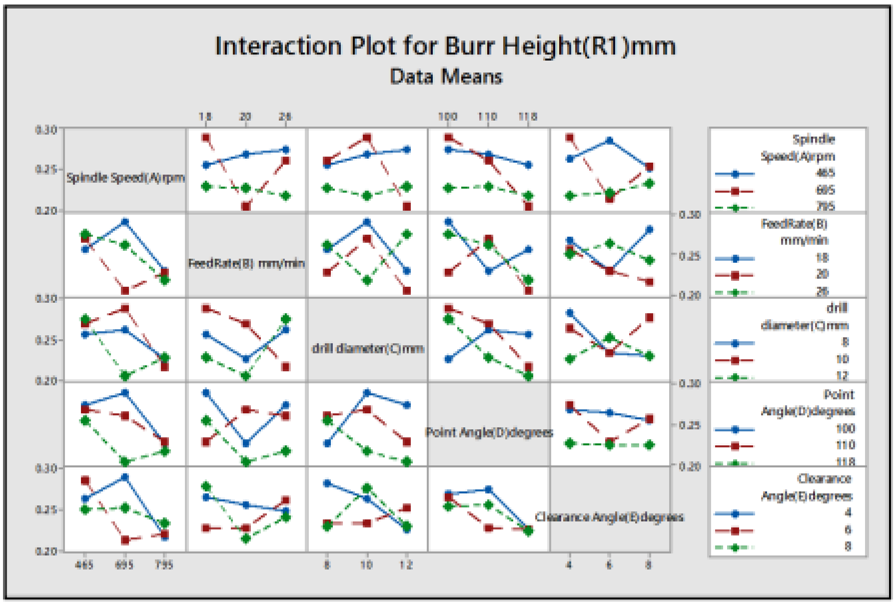

Fig.12: Interaction plots for Burr Height (Al 6061)

Interaction of burr height over the input parameters for aluminium 6061 alloy plotted in the Fig.12 shows that the burr height is considered along the ordinate and level of input parameters are selected on abscissa, which is decreases from level 1 to level 3 for combined effect of spindle speed and feed but lower the clearance angle yields an increase in burr height.

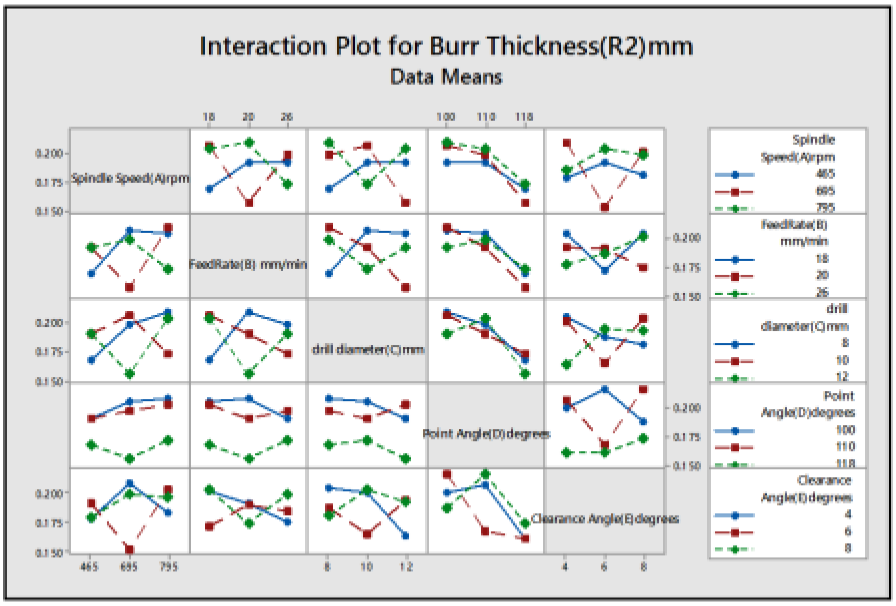

Fig.13: Interaction plots for Burr Thickness (Al 6061)

Interaction of burr thickness over the input parameters for aluminium 6061 alloy plotted in the Fig.13 shows that burr thickness is considered along the ordinate and level of input parameters are selected on abscissa, which is more interaction in the levels 1 and 2 for combined effect of point and clearance angle and also reveal less interaction in the level 3 of spindle speed, feed and drill diameter.

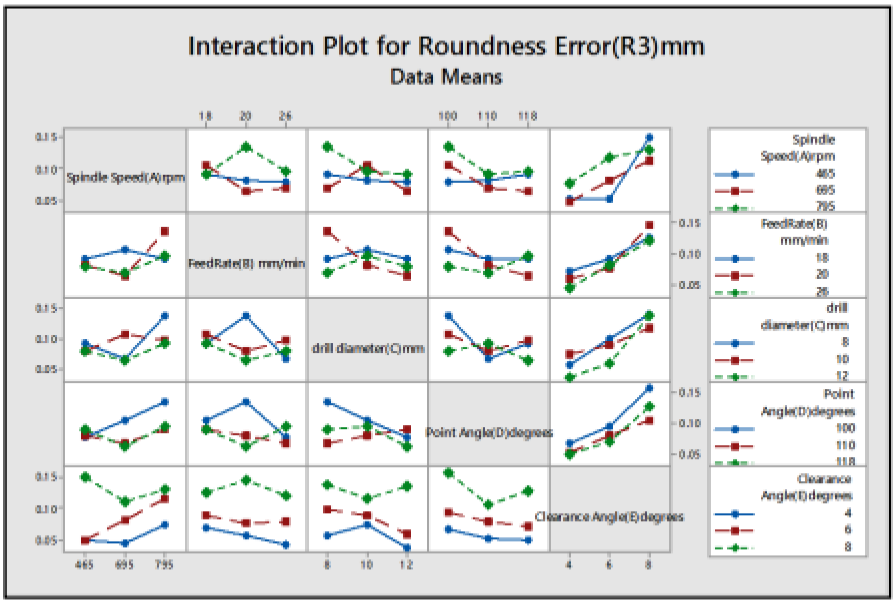

Fig.14: Interaction plots for Roundness Error (Al 6061)

The combined effect of parameters from level wise observed that from Fig.14, for moderate spindle speed and feed rates lowers the roundness error. Further it is observed that the clearance angle has less interaction with other parameters for aluminium 6061 alloy.

Interaction of thrust force over the input parameters for aluminium 6061 alloy plotted in the Fig.15 shows that thrust force is considered along the y-axis and level of input parameters are selected on x-axis, which is more interaction in the levels 1 and 2 for combined effect of point and clearance angle and also shows less interaction in the level 3 of spindle speed, feed and drill diameter.

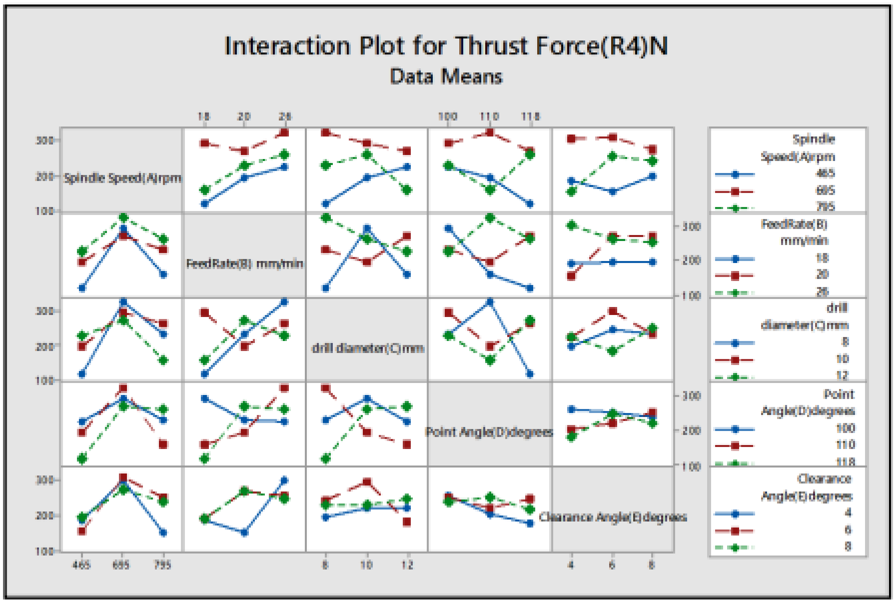

Fig.15: Interaction plot for Thrust force (Al 6061)

Interaction of torque over the input parameters for aluminium 6061 alloy plotted in the Fig.16 shows that torque is considered along the ordinate and level of input parameters are selected on abscissa, which has less interaction in the levels 1 and 2 for combined effect of point and clearance angles and also reveal more interaction in the level 3 of spindle speed, feed and drill diameter.

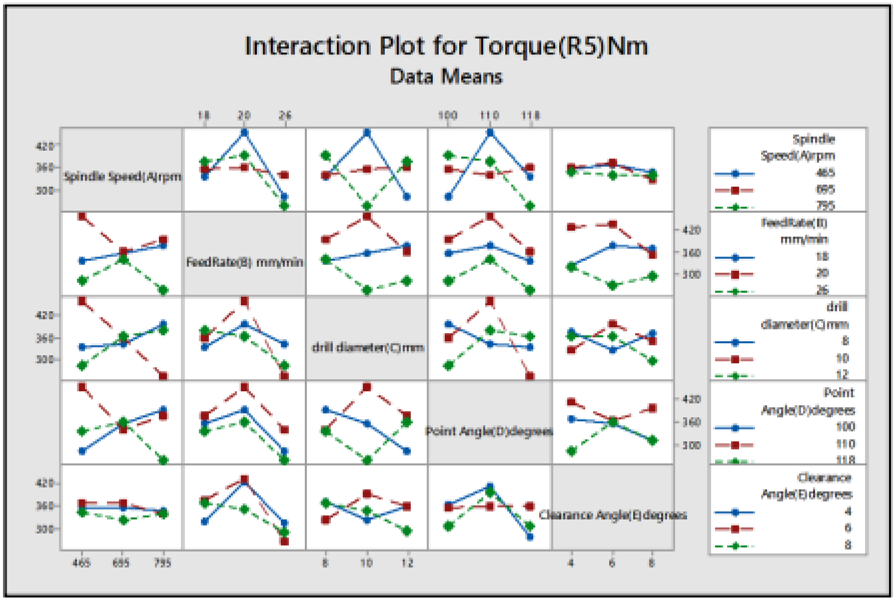

Fig.16: Interaction plot for Torque (Al 6061)

Interaction of surface roughness over the input parameters for Al 6061 alloy plotted along the ordinate and level of parameters are selected on abscissa shown in Fig.17 as reveals that the less interaction in the levels 1 and 3 for combined effect of speed and clearance angle and also shows more interaction in the level 2 of feed and drill diameter.

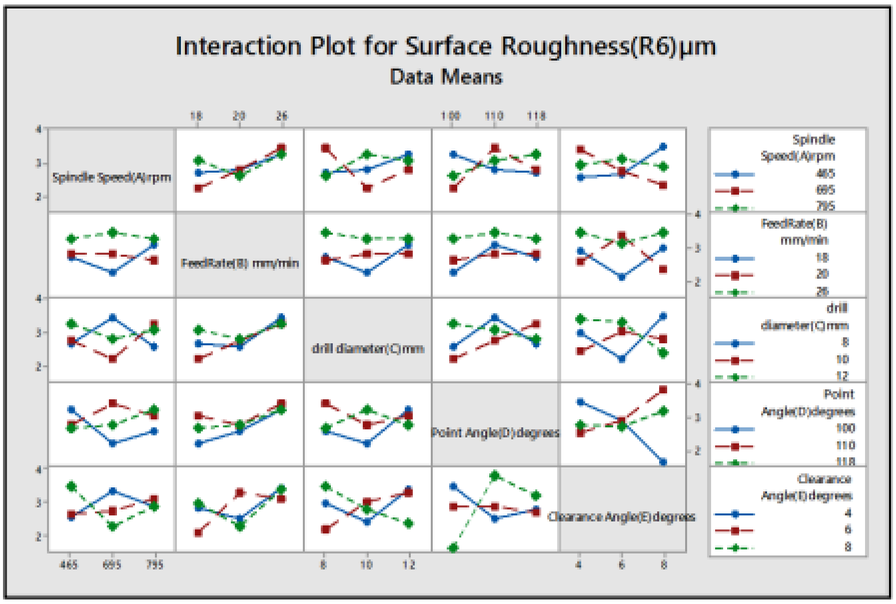

Fig.17: Interaction plot for Surface Roughness (Al 6061)

Conclusion: The conclusions obtained from the present work performed to evaluate burr size (height and thickness), roundness error, thrust force, torque and surface roughness during experimentation. The experimental results reveal that the feed rate, point angle and clearance angles are the most influencing parameters on burr height, thrust force, roundness error and surface roughness than the spindle speed and drill diameter for Al 6061 alloy. It deduced from the interaction plots obtained from ANOVA using Minitab@17 software divulges that the combined influence of each input parameter over the other parameters on multiple output characteristic responses. Therefore, the present work confirms that in drilling of Al 6061 alloy for all cutting conditions tested and the burr height, burr thickness, roundness error, thrust force, surface roughness and torque are close to those obtained in drilling experimentation respectively as 6.45%, 5.92%, 5.55%, 5.86%, 4.64% and 5.88% in that order mentioned above has been enhanced for Al 6061 alloy.

Future Scope: The study could be extended for drilling of Aluminium alloys namely Al 6061 alloy with HSS twist drill bit, there is a lot of scope for future investigation.

- The micro structural changes can have high impact on mechanical properties hence there is a scope to carry out research in this area.
- The different combinations of drill bit geometries may be attempted to find out economic viability.

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