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Burr formation minimization in drilling process using experimental study with statistical analysis

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ABSTRACT

Burrs are generally plastic deformation of the work piece after machining process. Deburring can reduce burr formation but it is time consuming and increase the production cost. By changing some of the input parameters like Spindle Speed, Feed Rate, Depth of Cut, the formation of burr can be reduced. This research work presents an experimental study on minimizing the formation of burr in machining like drilling. In this thesis, the Universal Radial machine has been used to make holes. By changing machining variables like feed, cutting velocity and speed different sizes and the type of the burrs created in aluminium are studied. Taguchi analysis has been done to analyze the predicted minimum burr height. ANOVA has also been done to analyze the maximum contribution of the parameters to form the burr. Signal to Noise(S/N) ratio plots has been shown in this research. Response surface methodology also has been conducted. In the design optimization, the application of RSM is aimed to reduce the cost of the expensive analysis methods (e.g. finite element method or CFD analysis) and their associated numerical noise.

Keywords— *Burrs, Universal radial machine, Taguchi method, ANOVA, S/N Ratio, Response surface methodology, Deburring*

1. INTRODUCTION

Recently, many researchers have focused on the problems associated with burr formation in the machining process. The focus has traditionally been on deburring processes but understanding the burr formation process is critical to burr prevention. Drilling a hole usually because of an undesirable burr at the exit work surface. Application of the method suggested by Taguchi is made to minimize drilling burr of an aluminum alloy using HSS drill. Being Aluminum a composite material its every component holds its own identity and maintains its characteristic structure and property. So, different sizes of burrs are formed during machining like drilling. Based on experimental data, Graphical representations of the parameters like Feed rate and depth of Cut are plotted against the height of the burrs. The experimental study was conducted as per the L27 orthogonal array of Taguchi method to find the optimum drilling parameters, and analysis of variance (ANOVA) was performed to investigate the influence of parameters on the burr height of composites during drilling.

In this regard, David Dornfeld [1] has researched a preventive and minimizing strategy of burr formation. Minimization of Burr by Providing Back-up Support on Aluminum Alloy with optimized drilling parameters has been studied by Sanjib Kundu, Santanu Das, Partha Pratim Saha, [2]. Study of parametric optimization of burr formation in step drilling of eutectic Al–Si alloy–Gr composites has been proposed by Palanisamy Shanmughasundarama, Ramanathan Subramanian [3]. Olvera and Barrow [4] analysed the formation of exit burrs and the top burrs in square shoulder face-milling. Narayanaswami and Dornfeld[5,6] developed an algorithm to minimize burr formation in face-milling of arbitrarily shaped polygons. Artificial Neutral Network (ANN) and Particular Swarm Optimization (PSO) is used by Gaitonde and Karnik [7] to find out the optimum drilling parameters to achieve minimum burr size during the drilling process. A deburring operation has been suggested by Tankazawa [8] and Gellespie[9].An investigation on Roll over burr has been done by Kishimoto et al. [10]. Liu, D., Tang, Y. and Cong, W. L. [11] has researched on the burr formation during the drilling process for a composite material. Pande, S.S. and Relekar [12] have investigated to reduce the formation of burr in drilling which has been published in International journal of Machine Tools & Manufacture. Pirtini, M. and Lazoglu, I., [13] researched Drilling forces and the holes created by the drilling operation. Kim, J. and Dornfeld, David A [14] have estimated the cost of drilling operations by a Drilling burr Control Chart and Bayesian Statistics. Ko, Sung-Lim and Lee, J., [15] has introduced a new concept of drill for the analysis of burr formation. Burr size reduction techniques are also has been researched with ultrasonic assistance in drilling by Chang, S and Bone [16]. Application of the method suggested by taguchi is made in this work to minimize drilling burr of an aluminum alloy of experiments considered.

The above literature surveys show that the burr formation minimization in a drilling process has been studied and experimented widely using experimental data and analytical modeling. Mechanism of burr formation work has been reported [17-20]. The methods of the predicted burr height in machining of various metals have also been reported in the survey [21-23].

Parameters used are cutting velocity, feed and machining environment. The optimum condition for minimizing burr height using a backup support is determined by the analysis. Analysis of variance (ANOVA) to be used for finding out the influence of process parameters in the final submission. Predicted values will be finally checked for accuracy through a confirmation test. Finally, the process of minimizing the burr height by using a backup support has been shown. After each experiment, the drilled plates are removed from the machine and the burr heights are measured by using vernier calliper.

2. INTRODUCTION TO DESIGN OF EXPERIMENTS

The word “experiment” is meant to describe that the system which is studying by the investigator is under the control of the investigator. To investigating something about any process there is a number of experiments required for finding the desired result in a condition of large input parameters. So to obtain an optimum result and to reduce the number of experiments the design of experiments is a highly recommended method all over the world.

The design of experiments is the most recommended and mostly uses tool for designing high-quality experiment at a reduced cost. This useful tool design of experiment was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agricultural Field research station in London, England. He was implementing this method for determining the effect of various fertilizers on different plots of land.

The purpose of Design of the experiment is to plan, design and analyze the experiment so that the valid and objective conclusion can be drawn efficiently and effectively.

The Taguchi method and the Response Surface Methodology have been introduced. A brief study of these two methods has been discussed below.

Taguchi methods are an actually statistical method, or generally, it is called a robust design method, which is developed by Genichi Taguchi for the improvement of the quality of manufactured goods. This method is recently also applied to engineering, biotechnology, marketing and advertising, etc. Professional Statistician greeted this technique for the goals and improvements brought by Taguchi Method, particularly for the study of variation, Taguchi's design developments are used but some of Taguchi’s proposed theorems are criticized by the statisticians for the in-built inefficiencies of this method.
Taguchi’s method contributed three major principles in statistics:

- A specified loss function
- The off-line control method philosophy, and
- The innovative design of experiments.

Experimental design is based on the Taguchi orthogonal array method, burr height has been used as the output of the project. On the other hand, spindle speed, feed rate, depth of cut, drill bits diameter, and point angle have been used as the independent (input) variables. Here we are using the Innovation in the design of experiments.

In the Taguchi OA design, only the main effects and two-factor interactions are considered, and higher-order interactions are assumed to be non-existent. In addition, the designer is asked to identify (based on their knowledge of the subject matter) which interactions might be significant before conducting the design. A standard Taguchi Experimental array with notation L_{27} was chosen for this experiment. Before that in table 1, there is a list of input variables.

2.1 Taguchi’s contribution in DOE

Taguchi’s method is a study based on the orthogonal array which is a fractional factorial array in Design of experiments. Taguchi developed a system of tabulated design which reduces the number of experiments as compared to full factorial design to show that it is not necessary to consider the interaction between two design variables. The advantage of the Taguchi’s proposed system was to handle discrete variables and the disadvantage is he ignores the interaction between variables.

Taguchi method which is a powerful tool in the design of an experiment is used to optimize the drilling parameters for effective machining of the aluminum alloy. This method recommends using of S/N ratio to measure the smallest height of the burrs. To obtain optimum testing parameters, the smaller-the-better quality characteristic for machining the aluminum was taken due to the measurement of the smallest height of the burr. The analysis is sufficient to investigate the three main effects and influence of their interactions on the burrs height. With S/N ratio analysis, the optimal combination of the testing parameters could be determined. The control parameters are Spindle Speed (S), Feed Rate (f), Depth of Cut (d). The orthogonal array L_{27} was chosen, which has 27 rows. Table 1 shows the input parameters chosen for the experiment.

2.2 Response surface methodology

Response surface methodology (RSM) is a unique method of model building by mathematical and statistical techniques. The objective is to optimize the output variable which is the response influenced by several input variables which are also independent variables by means of careful design experiments. An experimental series of test which is called runs, the changes are made in the input variables to identify the cause of changes in the output response.

Originally, for the modeling of the experimental responses, RSM was developed and migrated into the modeling of numerical responses. Only the type of the generated error is different. In physically held experiments, for example, the generation of the inaccuracy can be a result of errors due to measurement while, in computerized experiments, generation of numerical noise can be a result of incomplete convergence of iterative processes, round-off errors or the discrete representation of continuous physical phenomena[24]. It is assumed that the errors are random in RSM.

In the design optimization, the application of RSM is aimed to reduce the cost of the expensive analysis methods (e.g. finite element method or CFD analysis) and their associated numerical noise.

The graphical representation of the response is possible, either in 3-dimensional space or as contour plots to visualize the shape of the response surface. Contours are generally constant response curves which are drawn in the vertical and horizontal plane keeping all other variables fixed. A particular height of the response surface corresponds to each contour plots.

2.3 Response surface contribution in the design of experiments

The important aspect of RSM is the design of experiments, usually termed as DOE. For the model fitting of physical experiments, these strategies were originally developed, but can also be applied to numerical experiments. The objective of DOE is basically the selection of the points where the response should be evaluated. Most of the optimal design criteria of experiments are associated with the mathematical model of the process. The choice of the DOE can have a large influence on the accuracy of the approximation and the cost of constructing the response surface.

In a traditional DOE, in the early stages of the process, screening experiments are performed and at that time many of the design variables initially considered have little or no effect on the response. The purpose of DOE is basically to identify the design variables that have large effects for further investigation.

A detailed description of the design of experiments theory can be found in the journal Box and Draper [25]. Myers and Montgomery, Montgomery, among many others. The use of several designs and optimization of multidisciplinary design has been discussed by Unal et al. [26] and Simpson et al. [27] presented a complete review of the use of statistics in design for response surface methodology. Schoofs [28] has reviewed the application of experimental design to structural optimization. In this thesis, the DOE played an important role in the measurement of the height of the burr by RSM. The values were put in different sections of the application used. By putting the height of the burr as response value in the response value section and other remaining parameters in the fixed values section, contour plots are created. The design of experiment has used another design named as Full Factorial Design which has been discussed below.

3. EQUATIONS

In the present investigation, analysis of S/N ratio was done with burr height as the performance characteristic. Calculations were done using a software and have been shown in the Experimental table 2, table 3. For the minimization of burr height, the S/N ratio was calculated using smaller-the–better criterion.

In Taguchi method, the term "signal" expresses the desired value (mean) and the term "noise" expresses the undesired value (standard deviation) for the output quality characteristics. The mathematical equation of the S/N ratio for "smaller-is-better" is represented in the equation below.

$$\frac{S}{N} = -10\log[\frac{1}{n}\sum y^2]$$

Where y is the observed burr height and n is the observation number.

Below the S/N ratio smaller-the-better ranking tables, S/N ratio plots, the response of Means plot and the interaction plots for different input parameters are shown.

4. FIGURES

Figures should be pasted within the text column as follows.

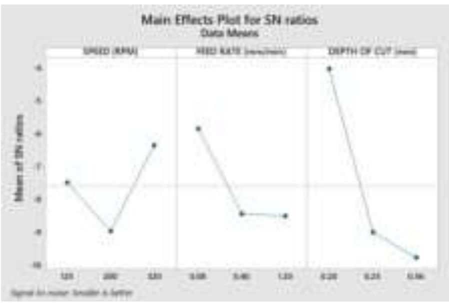


Fig. 1: Height of burr vs. Speed, feed rate and depth of cut

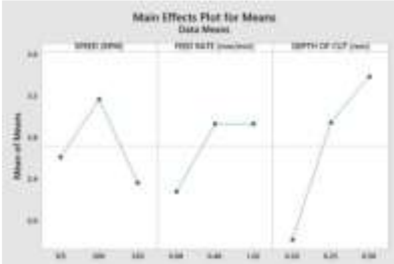


Fig. 2: Height of burr vs. Speed, feed rate & depth of cut

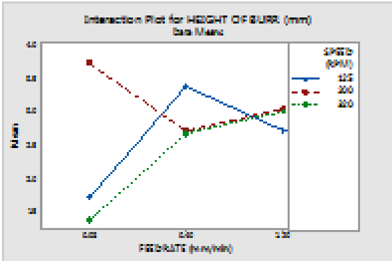


Fig. 3: Interaction plot for the height of burr showing the interaction between speed and feed rate

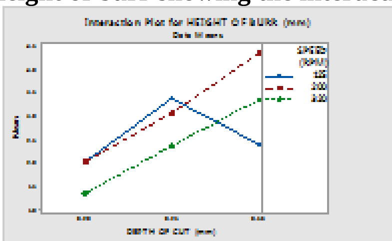


Fig. 4: Interaction plot for the height of burr showing the interaction between the speed and depth of cut

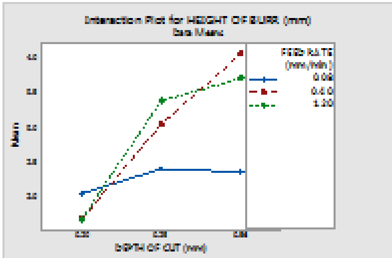


Fig. 5: Interaction plot for the height of burr showing the interaction between feed rate and depth of cut

The height of the burr vs. the input parameters spindle speed, feed rate and depth of cut are shown in the S/N ratio plot in figure 1 and Means Plot in figure 2. The interaction between the Speed and Feed rate in the formation of the burr for this particular experiment has been shown in figure 3. The Interactions between the Speed and depth of Cut and feed rate and Depth of Cut are shown in figure 4 and figure 5 respectively. The S/N ratio plot has been plotted using the smaller-the-better function. In the S/N ratio plot, the highest point shows the minimum burr height formation input parameters value. The Means plot is exactly the opposite of the S/N ratio plot. Here in the means plot, the lowest points show the input parameter values for creating the minimum height of the burr. From the above figures it can be concluded that the minimum height of the burr lies in 320 rpm speed, 0.08 mm/min Feed rate and 0.20 mm depth of cut. All the values that have been shown are all done in the experiment at the dry environmental condition.

In the case of interaction plots, the non-parallel line indicates the presence of interaction while the parallel line indicates a strong interaction. From figure 4, it is clear that there is a strong interaction between the parameters speed and Depth of cut while moderate interactions existing within the rest of the factors in figure 4 and 5 corresponding to the burr height of the aluminum alloy.

In the present investigation, analysis of S/N ratio was done with burr height as the performance characteristic. Calculations were done using a software. For the minimization of burr height, the S/N ratio was calculated using smaller-the-better criterion.

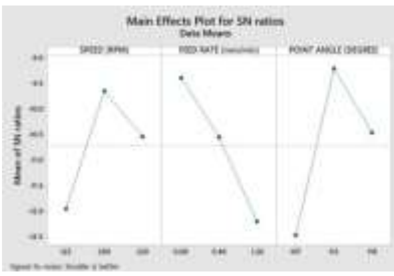


Fig. 6: Height of burr vs. speed, feed rate and point Angle

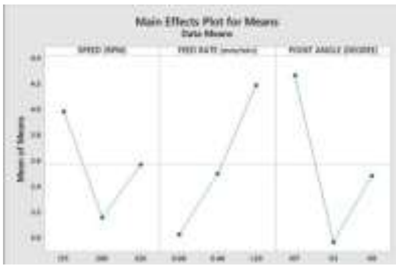


Fig. 7: Height of burr vs. speed, feed rate and point angle

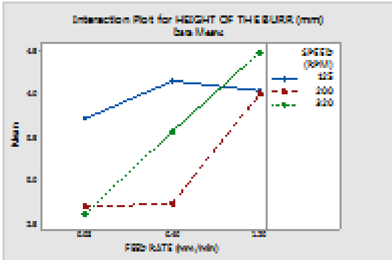


Fig. 8: Interaction plot for the height of burr showing the interaction between speed and feed rate

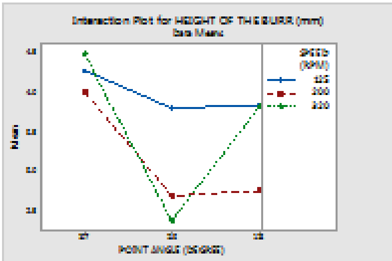


Fig. 9: Interaction plot for the height of burr showing the interaction between speed and point angle

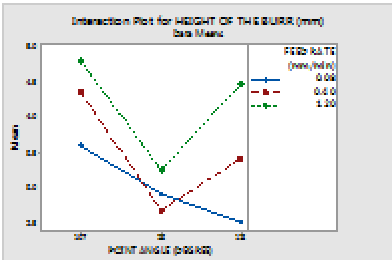
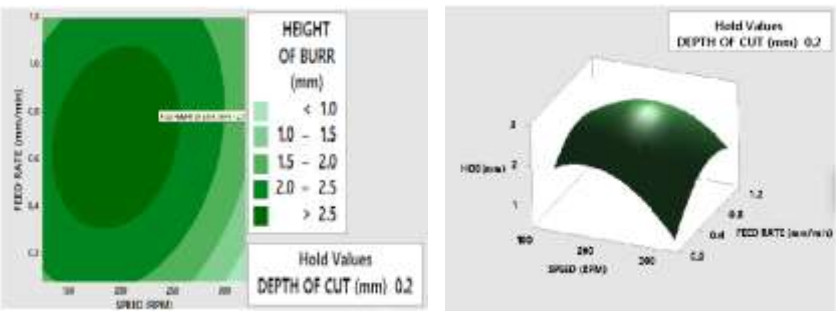


Fig. 10: Interaction plot for the height of burr showing the interaction between feed rate and point angle

The S/N ratio plot and the plot of means are shown in the above figure 6 and figure 7 respectively. The interaction between the Speed and Feed rate in the formation of the burr for this particular experiment has been shown in figure 8. The Interactions between the Speed and Point Angle and feed rate and Point Angle are shown in figure 9 and figure 10 respectively. Here in the S/N ratio plot, the highest points indicate the input parameter values which causes the minimum height of the burr. Similarly, in the means plot, the lowest points indicate the values of the input parameter resulting in the minimum height of burr. From both the above plots it can be concluded that the minimum predicted the height of burr lies in the spindle speed of 200 rpm, the feed rate of 0.08 mm/min and point angle of 113 degrees of the drill bit.

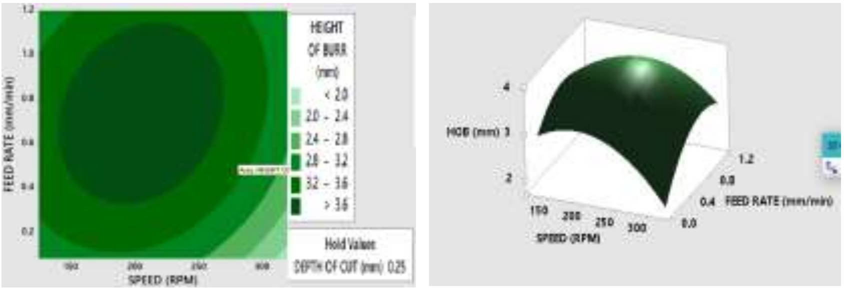
This section discusses the development of Response surface model using the values of burr height obtained from the experiment done on the aluminum work piece material. The statistical analysis of the burr height is also presented. This concludes by indicating the range of the minimum input variables to yield the minimum burr height.



(a) **(b)**

Fig. 11: (a) Contour plot of the height of burr for the dry condition with hold value of DOC 0.2, (b) Surface plot of the Height of burr for the dry condition with hold value of DOC 0.2

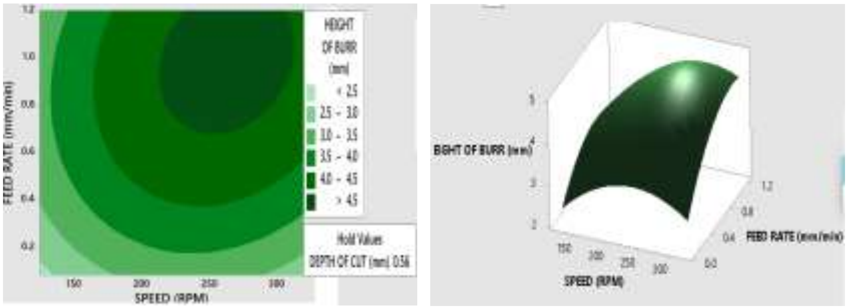
From figure 11(a), we can predict the minimum value of the burr height which is less than 1.00 mm. Here the experiment has been shown for the dry environmental condition with the hold value of the depth of cut 0.2 mm. In figure 11 (a), a predicted burr height is obtained in the range of 300 rpm and above speed and 0-0.2 range of feed rate. The figure 11(b) is showing the surface plot of the experiment done and from these surface plot, a predicted burr height is also obtained from the same range of speed and feed rate mentioned above for the case of the contour plot of figure 11(a).



(a) (b)

Fig. 12: (a) Contour plot of the height of burr for the dry condition with hold value of DOC 0.25 (b) Surface plot of the height of burr for the dry condition with hold value of DOC 0.25

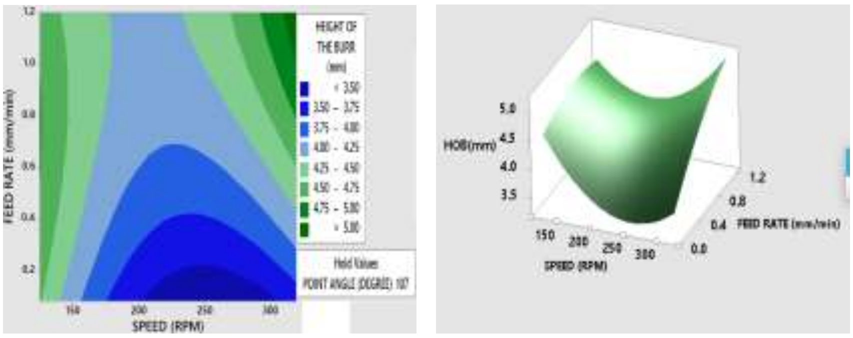
In the above figure 12 (a) the contour plot of the experiment done in the dry environmental condition with a hold value of the depth of cut 0.25 has been shown to obtain the predicted value of the minimum burr height. Here the minimum height of the burr that has been appeared in the plot is less than 2.0 mm. From the lower side of the very right corner of the contour plot the minimum burr height can be obtained in the spindle speed range of 300 rpm and above and the feed rate range of less than 0.2 mm. From figure 12 (b) the surface plot that indicates the predicted burr height obtained from the contour plot is right.



(a) (b)

Fig. 13: (a) Contour plot of the height of burr for the dry condition with hold value of DOC 0.56, (b) Surface plot of the height of burr for the dry condition with hold value of DOC 0.56

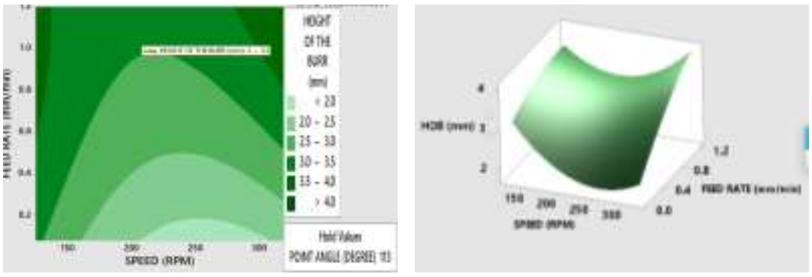
In figure 13 (a) the minimum burr height is predicted from the speed range of less than 150 and greater than 300 rpm. But for both the cases the feed rate range is less than 0.08. from the test value and the statistical value, it is obtained that for the speed range less than 150 rpm is responsible for creating the smallest burr for the dry environmental condition and hold the value of the depth of cut 0.56 mm. the figure 13 (b) shows the surface plot of the same case and from this plot, it is also found that the minimum value of the burr can be predicted from the speed range less than 150 rpm.



(a) (b)

Fig. 14: (a) Contour plot of the height of burr for the dry condition with hold value of point angle 107, (b) Surface plot of the height of burr for the dry condition with hold value of point angle 107

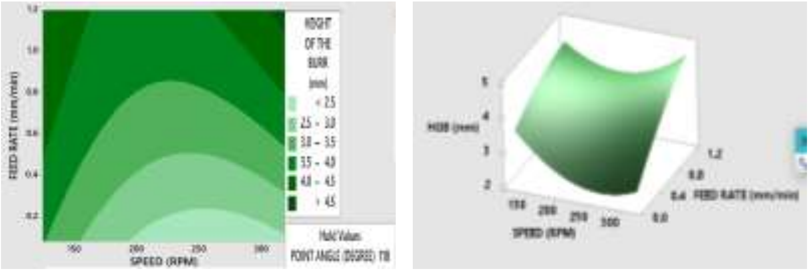
In these figure 14 (a) the minimum burr height is predicted using the hold value of the point angle 107 degrees. Here the minimum burr height can be predicted which is not greater than 3.50 mm between the speed ranging from 200-300 rpm and feed rate of less than 0.2 mm/min. from figure 14 (b) surface plot can help to obtain the predicted burr height in the same range mentioned above for the contour plot of figure 14 (a).



(a) **(b)**

Fig. 15: (a) Contour plot of the height of burr for the dry condition with hold value of point angle 113, (b) Surface plot of the height of burr for the dry condition with hold value of point angle 113

In these figure 15 (a), the contour plot shows that the predicted minimum height of the burr observed between the range of 200 – 320 rpm of the spindle speed and not greater than 0.2 mm/min for the feed rate for the dry experimental condition. In the surface plot (figure 15 (b)) also shows the same range of both the input parameters. From the experimental table 2.1, it is to be observed that the height of the burr including the range shown in this contour plot is minimum for the spindle speed of 320 rpm and 0.08 mm/min feed rate for the hold value of the point angle 113 degrees.



(a) **(b)**

Fig. 16: (a) Contour plot of the height of burr for the dry condition with hold value of point angle 118, (b) Surface plot of the height of burr for the dry condition with hold value of point angle 118

In these figure 16 (a) the contour plot shows that the predicted burr height is observed in the range between 200- 320 rpm of the spindle speed and less than 0.2 mm for the feed rate for the dry experimental condition. From the surface plot (figure 16 (b)) the same range can be observed for the minimum burr height prediction. From the experimental table, it is observed that the minimum burr height occurs at the spindle speed of 200 rpm.

The photographic views of the Experiment are showing below:

Fig. 17: Work piece before machining

Fig. 18: Work piece after machining at dry condition without back up support with varying depth of cut

Fig. 19: Work piece after machining at dry condition without back up support with a varying point angle

5. EXPERIMENTAL TABLES

The experimental input parameters are shown in table 1. These parameters are taken due to the fact that they are directly responsible for the formation of burr and by varying these parameters, the minimum height of the burr can be achieved.

Table 1: Input parameters of the experiment

Parameter	Level 1	Level 2	Level 3
Speed (rpm)	125	200	320
Feed Rate (mm/min)	0.08	0.4	1.2
Depth of cut (mm)	0.2	0.25	0.56

Table 2 shows the experimental data for the drilling process at dry condition without any backup support. Here the process parameters are Speed, feed rate, depth of cut and the response is the height of the burr, for this particular experiment the photographic view of the workpiece after machining is attached in figure 18. The following experimental table is arranged as per the Taguchi method and experiments have been done depending on different process parameter at a time.

Table 2: Experimental data for the drilling process at dry condition

Hole no	Speed (RPM)	Feed rate (mm/min)	The depth of cut (mm)	The height of burr (mm)	S/N Ratio
1	125	0.08	0.2	1.08	-0.668475
2	125	0.08	0.25	3.02	-6.589838
3	125	0.08	0.56	1.078	4.1188373
4	125	0.4	0.2	3.02	-3.579539
5	125	0.4	0.25	3.01	-2.5816
6	125	0.4	0.56	4.16	-4.6003
7	125	1.2	0.2	2.06	2.173635
8	125	1.2	0.25	4.14	-3.3091
9	125	1.2	0.56	2.008	3.487151
10	200	0.08	0.2	4.08	-2.213203
11	200	0.08	0.25	3.14	0.475333
12	200	0.08	0.56	4.004	-1.258069
13	200	0.4	0.2	1.06	10.63332
14	200	0.4	0.25	3.08	1.690266
15	200	0.4	0.56	4.024	-0.332246
16	200	1.2	0.2	1.02	11.8692
17	200	1.2	0.25	3.02	2.704350
18	200	1.2	0.56	5.14	-1.666537
19	320	0.08	0.2	1.04	12.44687
20	320	0.08	0.25	1.08	12.34182
21	320	0.08	0.56	2.06	6.944848
22	320	0.4	0.2	1.02	13.25222
23	320	0.4	0.25	3.06	3.90285
24	320	0.4	0.56	4.02	1.717591
25	320	1.2	0.2	2.02	7.872372
26	320	1.2	0.25	3.02	4.549595
27	320	1.2	0.56	4.02	2.229116

Table 3 shows the experimental data for the drilling process at dry condition without any backup support. Here the process parameters are Speed, feed rate, point Angle and the results are the height of the burr, for this particular experiment the photographic view of the workpiece after machining is attached in figure 19. The following table is arranged as per the Taguchi method and experiments have been done depending on different process parameter at a time.

Table 3: Experimental data for the drilling process at dry condition

Hole no	Speed (RPM)	Feed rate (mm/min)	Point angle (DEG)	The height of the burr (mm)	S/N Ratio
1	125	0.08	107	4.02	-12.084
2	125	0.08	113	4.02	-9.0742
3	125	0.08	118	3.16	-5.2225
4	125	0.4	107	5.1	-8.1
5	125	0.4	113	3.39	-3.6142
6	125	0.4	118	4.02	-4.3030
7	125	1.2	107	3.76	-3.0527
8	125	1.2	113	4.03	-3.0752
9	125	1.2	118	4.4	-3.3266
10	200	0.08	107	3.39	-0.6039

11	200	0.08	113	2.71	1.7545
12	200	0.08	118	2.05	4.5567
13	200	0.4	107	4	-0.9017
14	200	0.4	113	2.02	5.3542
15	200	0.4	118	2.25	4.7172
16	200	1.2	107	4.67	-1.3451
17	200	1.2	113	3.39	1.7004
18	200	1.2	118	4	0.5115
19	320	0.08	107	3.45	2.0311
20	320	0.08	113	2.08	6.6490
21	320	0.08	118	2.39	5.6542
22	320	0.4	107	4.02	1.3397
23	320	0.4	113	2.69	5.02223
24	320	0.4	118	4.04	1.6744
25	320	1.2	107	6.02	-1.6125
26	320	1.2	113	2.4	6.5
27	320	1.2	118	5.07	0.2134

5.1 Analysis of variance

In this section of the research, the ANOVA is done to find out the parameters which affect the formation of the height of a burr and the interacting parameters which also have a contribution in the formation of the burr. The process parameters those who have not any effect on the burr height formation can be eliminated from the optimization model. The percentage contribution of variance can be calculated using ANOVA. In this work, ANOVA is performed using the height of burr as the response, and results are shown in below table 3, table 4, table 5 and table 6. The ANOVA tables indicate F-values and P-values. In this table, significant factors and their interactions are analysed. If the obtained F-value of a parameter or interaction is equal to 0.05 for the same condition, then that particular parameter or interaction is considered to have a significant influence on the process response.

In table 3 it shows that Depth of Cut is the most significant parameter in the formation of burr with 95.5% confidence, then the Feed rate is much significant in the burr formation but the parameter Speed has less significance on burr height. Among the interactions, the interaction between the speed and feed rate has significance on burr height, the others are not significant.

Table 4: Depth of Cut

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed (RPM)	2	3.048	1.5216	1.64	0.253
Feed rate (mm/min)	2	2.551	1.2757	1.96	0.203
Depth of cut (mm)	2	11.785	5.8924	7.57*	0.014
Speed (RPM)*Feed rate (mm/min)	4	7.771	1.9428	2.50	0.126
Speed (RPM)*Depth of cut (mm)	4	5.349	1.3373	1.72	0.238
Feed rate (mm/min)*Depth of cut (mm)	4	3.968	0.9921	1.28	0.356
Error	8	6.224	0.7780		
Total	26	40.692			
DF= Degree of Freedom, Adj SS= Adjusted Sequential Square of Sum, Adj MS= Adjusted sum of Square					

So, at the dry environmental condition, the depth of cut is the most significant parameter on burr height formation for this particular experiment. The interaction between the speed of the spindle and the feed rate is the most significant interacting parameter among all.

In table 4 it shows that Point Angle is the most significant parameter in the formation of burr with 99.99% confidence, then the Feed rate is much significant in the burr formation but the parameter Speed has less significance on burr height. Among the interactions, the interaction between the speed and Point Angle has significance on burr height, the others are not significant.

Table 5: Point Angle

Analysis Of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Speed (RPM)	2	3.059	1.5294	4.77*	0.043
Feed rate (mm/min)	2	6.160	3.0802	9.61*	0.007
Point angle (degree)	2	7.712	3.8558	12.03*	0.004
Speed (RPM)*feed rate	4	2.618	0.6545	2.04	0.181
Speed (RPM)* Point angle(degree)	4	2.969	0.7423	2.32	0.145
Feed rate (mm/min)* Point angle (degree)	4	2.288	0.5719	1.78	0.225
Error	8	2.564	0.3205		
Total	26	27.370			
DF= Degree of Freedom, Adj SS= Adjusted Sequential Square of Sum, Adj MS= Adjusted sum of Square					

Response table for the signal to Noise Ratio for Dry Condition, Smaller the better.

Level	Speed (RPM)	Feed Rate (mm/min)	The depth of cut (mm)
1	-7.461	-5.823	-4.006
2	-8.951	-8.433	-8.978
3	-6.339	-8.495	-9.766
Delta	2.613	2.672	5.760
Rank	3	2	1

Response table for Signal to noise ratio for dry environmental condition smaller the better

Level	Speed (RPM)	Feed Rate (mm/min)	Point Angle (deg)
1	-11.942	-9.372	-12.467
2	-9.636	-10.538	-9.192
3	-10.532	-12.201	-10.451
Delta	2.307	2.829	3.275
Rank	3	2	1

6. RESULTS AND DISCUSSIONS FOR RSM

The response surface equation has been fitted using a Software for the response variable Height of the burr (H_B). The regression co-efficient for the minimum height of burr has been shown in Table 6 for Dry environmental condition. The equations have been given in terms of the uncoded value of the independent variables as shown below:

Height of burr (mm) H_{B1}= -6.49+0.0205 S+1.22 f +42.8 d –0.000072 S^2-1.82 f^2 –58.9 d^2+0.00445 S*f+0.0234 S*d+2.17 f*d (ii)

Height of burr (mm) H_{B2}= 384–0.0275 S–6.17 f–6.63 p+0.000074S^2–0.55 f^2+0.02909 p^2+0.00651 S*f–0.000099 S*p+0.0578 f*p (iii)

The equation (ii) is the Response surface regression equation of un-coded units where the input parameters are spindle speed (S), Feed Rate (f) and Depth of cut (d) and the response parameter is the height of the burr for the dry environmental condition which is indicated by HB1. Similarly, the equation (iii) is the Response surface regression equation of un-coded units where the input parameters are spindle speed (S), Feed Rate (f) and Point angle (p) and the response parameter is the height of the burr for the dry environmental condition which is indicated by HB2. Comparing the burr heights from RSM analysis and Taguchi S/N ratio analysis the final concluded predicted minimum burr height is shown in table 6 below.

Table 6: Test data set for the burr height for dry environmental condition

No	Spindle Speed (rpm)	Feed rate (mm/min)	The depth of Cut (mm)	Point Angle (degree)	Height of burr (mm) (H_{B1}, H_{B2})
1	125	0.08	0.56	-	2.31010
2	200	0.08	-	107	3.00054
3	320	0.08	0.2	-	0.63339
4	320	0.08	0.25	-	1.83124
5	320	0.08	-	113	1.94323
6	200	0.08	-	118	1.86328
7	200	0.08	-	113	3.34466
Min	**320**	**0.08**	**0.2**	**-**	**0.63339**

6.1 Observations from the RSM

So it is to be observed that the minimum burr height can be observed with the hold value of the depth of cut instead of point angle. So here the input parameters for the dry and wet environmental condition are Spindle Speed, Feed Rate, Depth of Cut. And the response or output is the minimum burr height. All the heights of the burr are in mm. The final conclusion of this research is that the minimum height of the burr is 0.63339 mm has been found at Spindle Speed 320 RPM, Feed Rate 0.08 mm/min and Depth of Cut 0.2 mm for Dry environmental condition. Though the above-mentioned heights are optimized through the equations got from the RSM, The experimental or practical height of the burr which is found after the final experiment was done with the values of the optimum input parameters is also shown in below.

Dry without backup Support– the input parameters are 320 RPM spindle speed, 0.08 mm/min Feed rate and 0.2 Depth of Cut. A photographic view has also been shown in figure 20. The practical height of the burr is 0.5359 mm.

Fig. 20: Drilling at dry condition without backup support

Dry with backup support– the input parameters are 320 RPM spindle speed, 0.08 mm/min Feed rate and 0.2 Depth of Cut. A photographic view has also been shown in figure 21. Here a wooden piece is used as a backup support. The practical height of the burr is 0.51054 mm.

Fig. 21: Drilling at the dry condition with backup support

7. CONCLUSION

This experimental study has reviewed the development work in progress to establish a comprehensive strategy for burr minimization. The prevention of bending increases the time taken for drilling operation to complete and the applied force will be limited. There is much additional work to be done as well as a collection of information from industry practice for database development and model verification. It is hoped that this approach will help to research work in the future. This project demonstrates how to use Taguchi parameter design for optimizing machining performance with minimum cost and time to industrial readers. This project has discussed an application of the Taguchi method for optimization the cutting parameters in drilling operations and an application of the RSM process to analyze the minimum burr height. As shown in this study, the Taguchi method and RSM provides a systematic and efficient methodology for the optimization of the minimum height of the burr with far less effect than would be required for the most optimization techniques. The study was done on Al alloy, the future work can be done using another material and other input factors like relief angle, point angle, chisel edge angle etc.

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