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OPTIMIZATION OF BURR SIZE, SURFACE ROUGHNESS AND CIRCULARITY DEVIATION DURING DRILLING OF AL 6061 USING TAGUCHI DESIGN METHOD AND ARTIFICIAL NEURAL NETWORK

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ABSTRACT

This paper presents the influence of cutting parameters like cutting speed, feed rate, drill diameter, point angle and clearance angle on the burr size, surface roughness and circularity deviation of Al 6061 during drilling on CNC vertical machining center. A plan of experiments based on Taguchi technique has been used to acquire the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate machining characteristics of Al 6061 using HSS twist drill bits of variable tool geometry and maintain constant helix angle of 45 degrees. Confirmation tests have been carried out to predict the optimal setting of process parameters to validate the used approach, obtained the values of 0.2618mm, 0.1821mm, 3.7451μm, 0.0676mm for burr height, burr thickness, surface roughness and circularity deviation respectively. Finally, artificial neural network has been applied to compare the predicted values with the experimental values, good agreement was shown between the predictive model results and the experimental measurements.

Keywords: Al 6061 Alloy, Drilling, Taguchi Design method, S/N ratio, ANOVA, Artificial Neural Network.

1. INTRODUCTION

Burr is plastically deformed material, obtained on the part edge during cutting or punching. Burr reduces the precision of products and causes additional cost of de burring, the burrs strongly influence the product quality and assembly. This additional procedure results in the high cost of the edge finishing of precision parts. Since de burring process is not well automated, the productivity of production systems is often reduced.

Understanding the drilling burr formation and its dominant parameters is essential for reducing burr. To provide cost effectiveness in production and especially in machining operations, there is a continuous necessity to decrease tooling costs. The most well- automated methods used to decrease tooling costs are various applications of more resistant cutting tool materials, heat treatment methods, cutting fluids used, speed and feed rates, and the development of coated inserts on cutting tools.

The surface roughness and roundness error are influenced by several factors which include cutting tool geometry, speed, and feed, structure of the work piece and the rigidity of the machine tool. These parameters affecting the surface roughness and whole qualities (roundness, cylindricality and whole diameter) can be optimized in various ways such as Taguchi and multiple regression methods.

Therefore, a number of researchers have been focused on an appropriate prediction of surface roughness and roundness error. Taguchi method has been widely used in engineering analysis and is a powerful tool to design a high quality system. By applying the Taguchi technique, time for experimental investigations can be reduced, as it is effective in the investigation of the influence of multiple factors on performance as well as to study the significance of individual factors to determine which factor has more influence, which one is less influence.

Yang and Chen (2001) used the Taguchi parameter design in order to identify optimum surface roughness performance on an aluminum material with cutting parameters of depth of cut, cutting speed, feed rate and tool diameter. It reveals that tool diameter is not a significant cutting factor influence on the surface roughness.

Davim and Reis (2003) presented an approach using the Taguchi method and ANOVA to establish a correlation between cutting speed and feed rate with the de

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lamination in a fiber reinforced composite. A statistical analysis of whole quality was performed by Furness, Wu and Ulsoy (1996) they found that feed rate and cutting speed have a relatively small effect on the measured whole quality features.

Tsao and Hocheng (2008) performed the prediction and evaluation of thrust force and surface roughness in drilling of fiber reinforced composite, the approach used is Taguchi and the neural network methods. The experimental results reveal that the feed rate and the drill diameter are the most significant factors affecting the thrust force, while the feed rate and spindle speed less significant but percentage contribution is more on the surface roughness.

Nalbant, Gokkaya and Sur (2007) utilized the Taguchi technique to determine the optimal machining parameters for surface roughness in turning of AISI 1030 steel with Ti N coated inserts on cutting tool. Three parameters such as radius of insert on cutting tool, feed rate, and depth of cut\are optimized for surface roughness.

Kurt, Bagci and Kaynak (2009) applied the Taguchi method in the optimization of process parameters for surface roughness and roundness error in dry drilling processes. The objective of this study is to investigate the effects of the drilling parameters on burr size, surface roughness average and circularity deviation and is to determine the optimal drilling parameters using the Taguchi design method and compared the results with neural network.

2. Experimental Procedure:

2.1. Material

Al 6061 is one of the 6000 series aluminum alloy used in the aircraft and aerospace components, marine fittings, bicycle frames, camera lenses, brake components, electrical fittings and connectors, valves, couplings etc. The composition of Al 6061 is 0.63% Si, 0.096% Cu, 0.091% Zn, o.466% Fe, 0.179% Mn, 0.53% Mg, 0.028% Ti, 0.028% Cr, and remaining aluminum. The young's modulus is 80 G pa and hardness 98 BHN. In this study 600x50x10mm rectangular bar was used.

2.2. Schematic machining:

In this study, the experiments were carried out on a CNC vertical machining center (KENT and ND Co. Ltd, Taiwan make) shown in figure.1 to perform different

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size of holes on Al6061 work piece by alter the point and clearance angles on standard HSS twist drill bits and maintain constant helix angle of 45 degrees. Furthermore the cutting speed (m/min), the feed rate (mm/rev) and percentage of cutting fluid mixture ratio are regulated in this experiment.

Figure 1: Drilling of Aluminium 6061 alloy

2.3. Measuring Apparatus

The burr size (thickness and height) is measured by digital profile projector. After measuring the burr size, the burr is removed then measured surface roughness and circularity deviation of drilled hole by a surface analyser of Talysurf 50 (Taylor Hobson Co Ltd) and coordinate measuring machine respectively.

3. MOTIVATION OF THE PRESENT WORK

3.1. Methodology

The orthogonal array forms the basis for the experimental analysis in the Taguchi method. The selection of orthogonal array is concerned with the total degree of freedom of process parameters. Total degree of freedom (DOF) associated with five parameters is equal to 10 (5X2).The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters.

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There by, a L27 orthogonal array having degree of freedom equal to (27-1) 26 has been considered, which is used to optimize the cutting parameters for burr size, surface roughness and circularity deviation using the S/N ratio and ANOVA for machining of Al 6061 alloy and predicted results were nearer to the experimental results.

Although similar to design of experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design. By Taguchi techniques, industries are able to greatly reduce product development cycle time for design and production, therefore reducing costs and increasing profit.

Also neural network technique has been applied to compare the predicted values with the experimental values and compared the error between experimental values. Finally, confirmation test have been carried out to compare the predicted values with the experimental values confirm its effectiveness in the analysis of burr size, surface roughness and circularity deviation.

3.2. Experimentation as per Taguchi Design Method

A plan of experiments based on Taguchi technique has been used to acquire the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the drilling characteristics of Al 6061 alloy using HSS twist drill bits. The complete procedure in Taguchi design method can be divided into three stages: system design, parameter design, and tolerance design.

Of the three design stages, the second stage – the parameter design – is the most important stage. Taguchi's orthogonal array (OA) provides a set of well-balanced experiments (with less number of experimental runs), and Taguchi's signal-to-noise ratios (S/N), which are logarithmic functions of desired output in the optimization process. Taguchi method uses a statistical measure of performance called signal-to-noise ratio.

The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The machining parameters and their levels are given in Table1. Plan of experiments based on Taguchi orthogonal array and observed responses shown in Table 2.

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Table1: Machining parameters and their levels

LEVELS	FACTORS				
	CUTTING SPEED (rpm)	FEED RATE (mm/min)	DRILL DIAMETER (mm)	POINT ANGLE (Degrees)	CLEARANCE ANGLE (Degrees)
	A	B	C	D	E
1	600	0.3	8	118	4
2	800	0.5	10	110	6
3	1000	0.6	12	100	8

Table 2: Plan of experiments based on Taguchi orthogonal array and observed responses

RUNS	TAGUCHI RESPONSE DESIGN TABLE									S/N Ratio
	cutting speed (rpm)	Feed rate (mm/ min)	drill dia (mm)	point angle (deg)	clearance angle (deg)	burr height (mm)	burr thickness (mm)	surface roughness (µm)	circularity deviation (mm)	
	A	B	C	D	E	R1	R2	R3	R4	
1	1	1	1	1	1	0.268	0.178	2.39	0.058	-1.6278
2	1	1	1	1	2	0.254	0.166	1.16	0.063	4.4320
3	1	1	1	1	3	0.248	0.161	4.5	0.152	-7.0672
4	1	2	2	2	1	0.287	0.208	1.25	0.064	3.7360
5	1	2	2	2	2	0.258	0.168	3.36	0.048	-4.5433
6	1	2	2	2	3	0.264	0.197	3.72	0.127	-5.4292
7	1	3	3	3	1	0.238	0.149	4.05	0.027	-6.1495
8	1	3	3	3	2	0.347	0.241	3.45	0.036	-4.8008
9	1	3	3	3	3	0.242	0.184	2.29	0.174	-1.2765
10	2	1	2	3	1	0.318	0.243	3.33	0.088	-4.4935
11	2	1	2	3	2	0.222	0.159	2.25	0.109	-1.0965
12	2	1	2	3	3	0.328	0.218	1.06	0.122	4.9026
13	2	2	3	1	1	0.228	0.156	3.26	0.019	-4.2749
14	2	2	3	1	2	0.200	0.151	3.60	0.041	-5.1270
15	2	2	3	1	3	0.187	0.164	1.56	0.132	2.0188
16	2	3	1	2	1	0.324	0.228	3.54	0.026	-5.0137
17	2	3	1	2	2	0.219	0.147	2.45	0.094	-1.8190
18	2	3	1	2	3	0.244	0.220	4.38	0.085	-6.8348
19	3	1	3	2	1	0.214	0.189	2.89	0.066	-3.2417
20	3	1	3	2	2	0.209	0.191	2.91	0.100	-3.3032
21	3	1	3	2	3	0.264	0.233	3.41	0.107	-4.6847
22	3	2	1	3	1	0.254	0.212	3.11	0.089	-3.8870
23	3	2	1	3	2	0.229	0.252	3.02	0.141	-3.6437
24	3	2	1	3	3	0.196	0.163	1.65	0.182	1.5171
25	3	3	2	1	1	0.186	0.152	2.72	0.072	-2.7075
26	3	3	2	1	2	0.223	0.169	3.46	0.111	-4.7936
27	3	3	2	1	3	0.241	0.198	3.59	0.105	-5.1176

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3.3. Analysis of the S/N Ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (Standard Deviation) for the output characteristic. Therefore, the S/N ratio to the mean to the S.D. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio (η) is defined as η = -10 log (M.S.D), Where M.S.D is the mean square deviation for the output characteristic.

Table 2 shows the experimental results for observed responses. The S/N ratio table for observed responses is shown in Table 3.

Table3. Signal to Noise Ratios for Smaller is better

Level	Cutting speed (rpm) A	Feed rate (mm/min) B	Drill diameter (mm) C	Point angle (Deg) D	Clearance angle (Deg) E
1	-2.52518	-1.79783	-2.66049	-2.10312	-2.44130
2	-2.41537	-2.18147	-2.17144	-3.45934	-2.74395
3	-3.31802	-4.27928	-3.42665	-2.69612	-3.07333
Delta	0.90265	2.48145	1.25522	1.35623	0.63203
Rank	4	1	3	2	5

4. RESULTS AND DISCUSSIONS

From main effects plot of S/N ratio for, the optimum parameters combination for burr height, burr thickness, surface roughness and circularity deviation are A2B1C2D1E1 corresponding to the largest values of S/N ratio for all control parameters. From Table 3, it is observed that feed rate, point angle, drill diameter, cutting speed and clearance angle has the order of influence on burr size, surface roughness and circularity deviation during drilling of Al6061 alloy.

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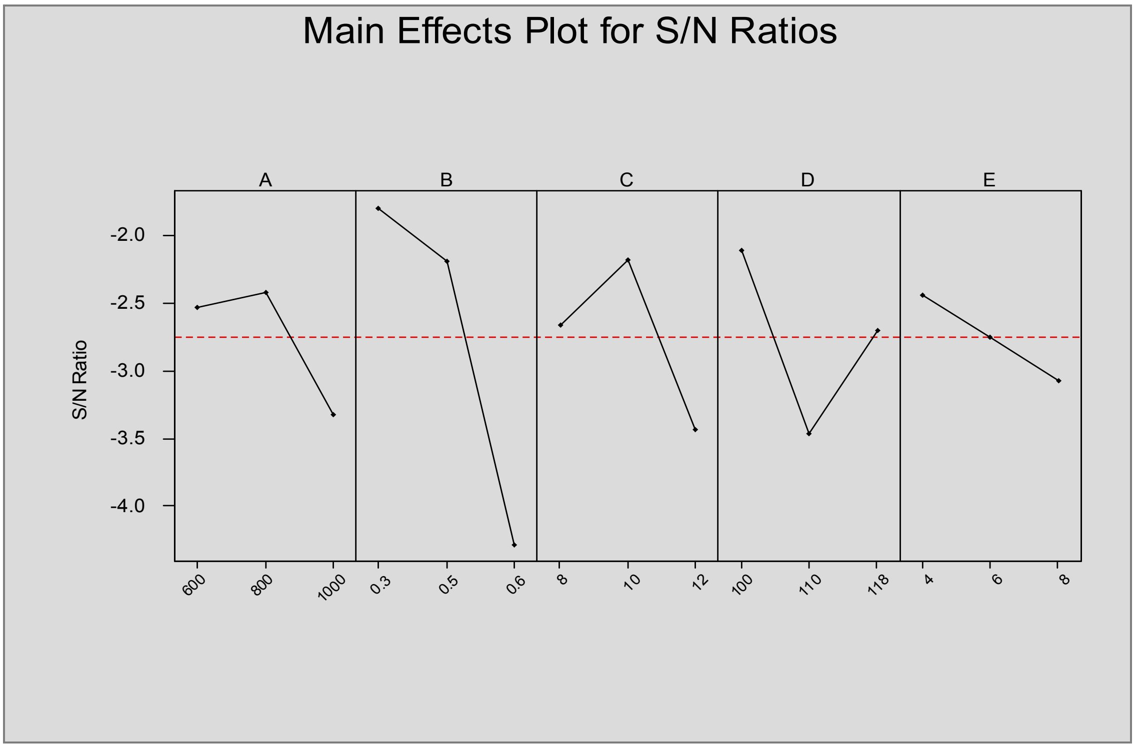

Figure 2: Main effects plot for S/N ratio

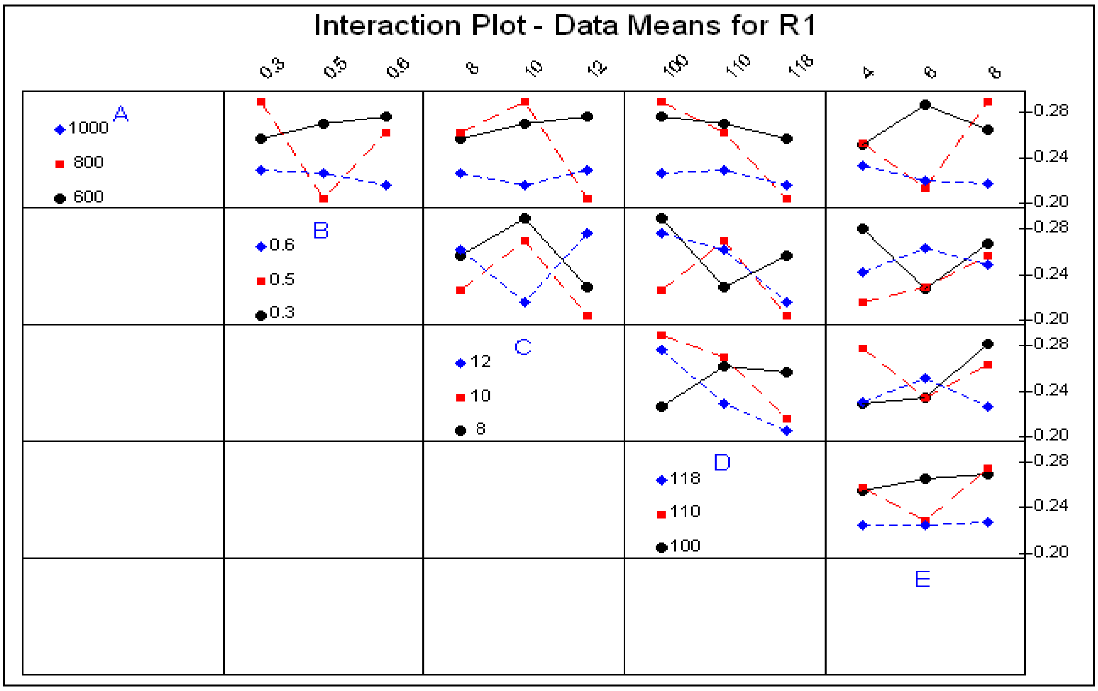

Figure 3: Interaction plot of burr height with effect of other parameters

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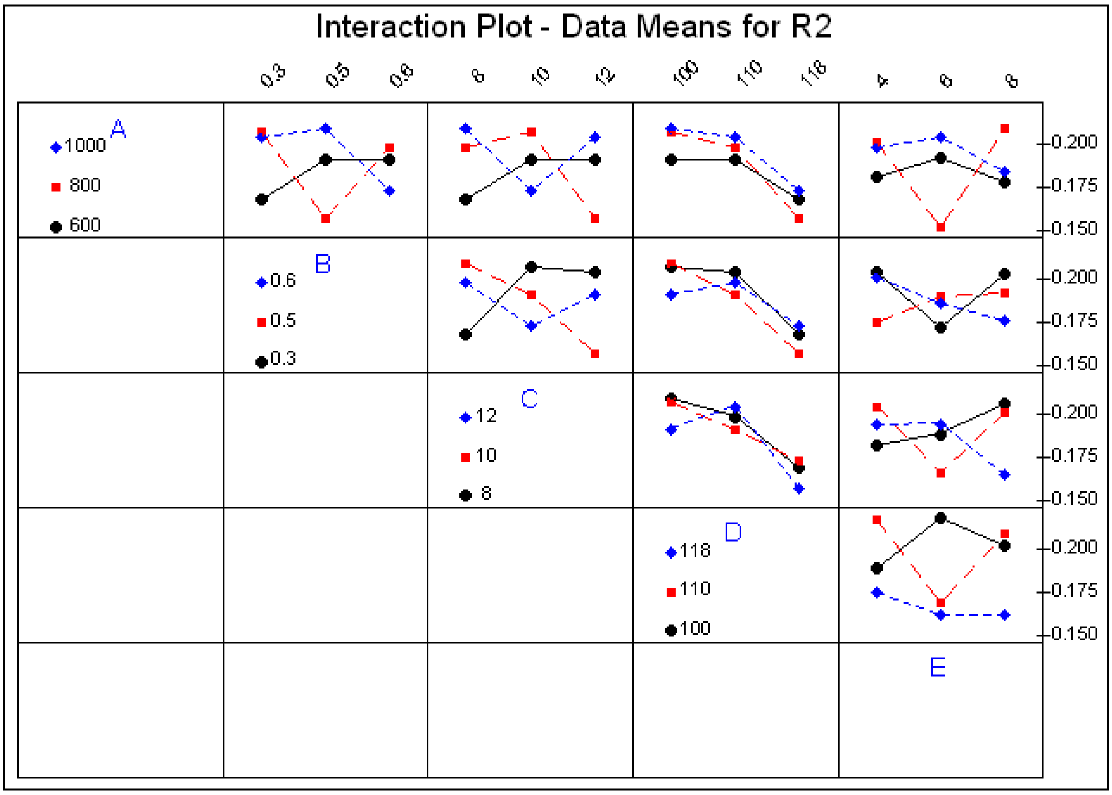

Figure 4: Interaction plot of burr thickness with effect of other parameters

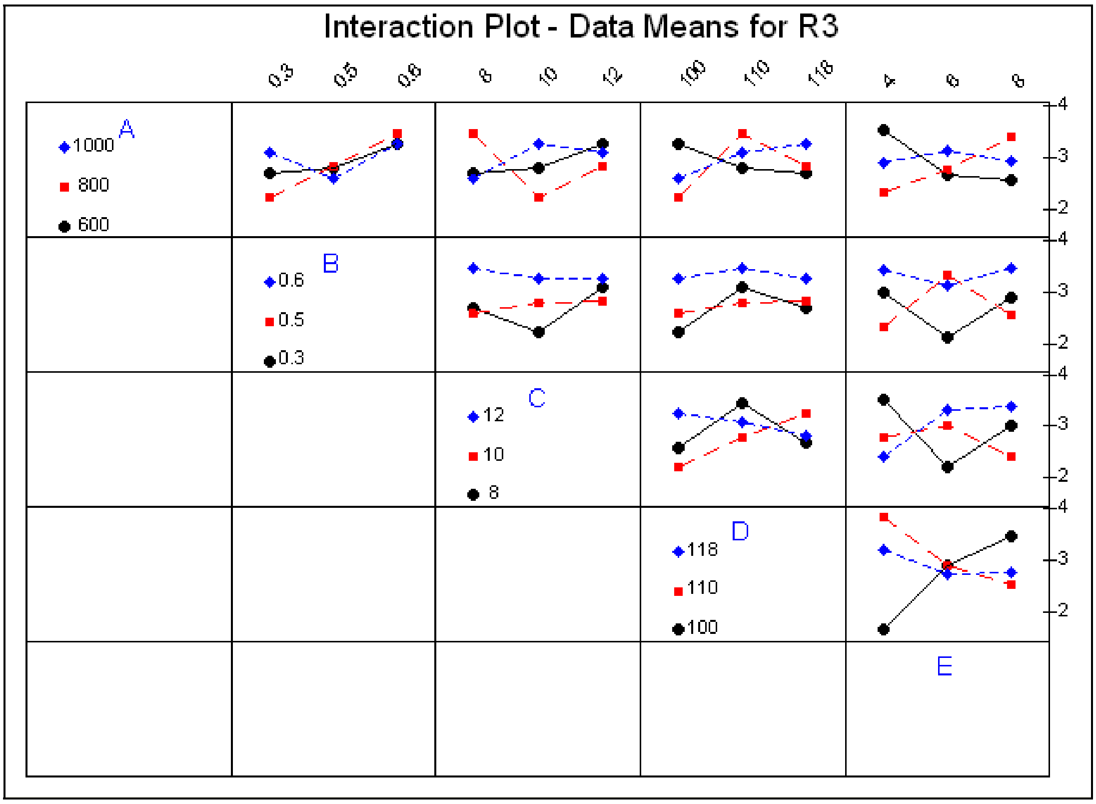

Figure 5: Interaction plot of surface roughness with effect of other parameters

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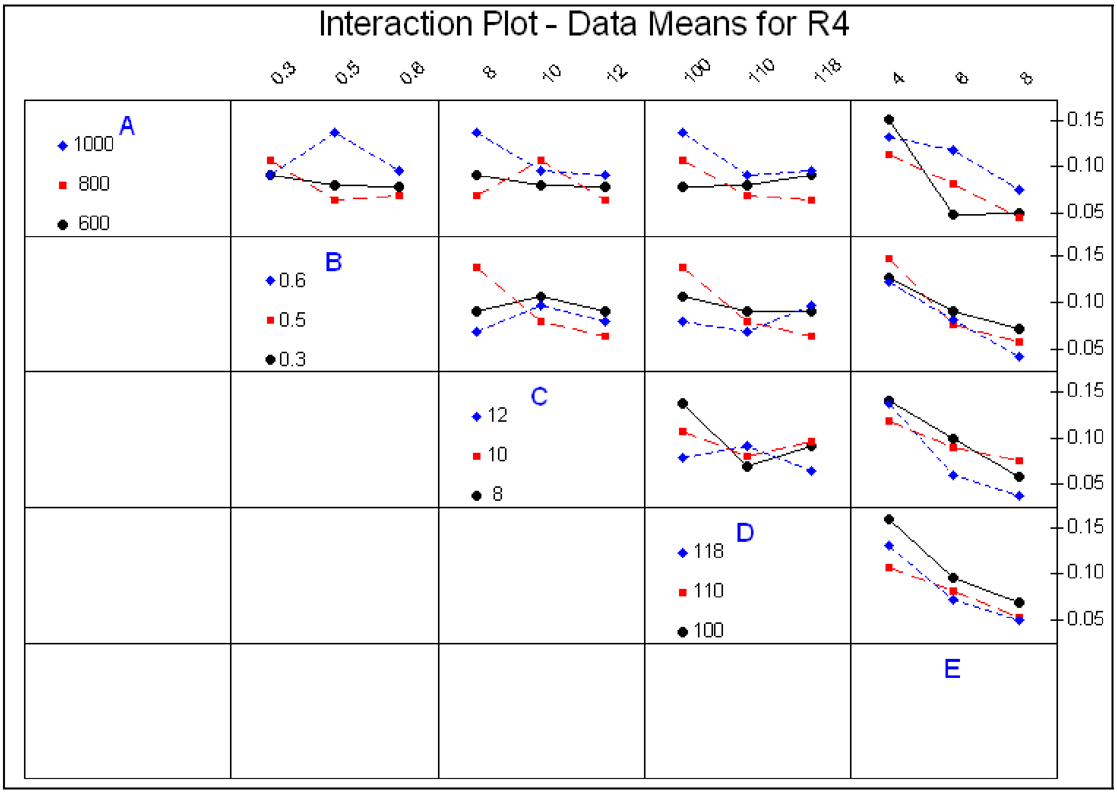

Figure 6: Interaction plot of circularity deviation with effect of other parameters

4.1. Results of ANOVA

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic.

Table 4 shows the results of ANOVA for burr height, cutting speed, feed rate, drill diameter, point angle and clearance angle are the significant cutting parameters for affecting the burr height.

Table 5 shows the results of ANOVA for burr thickness, cutting speed, feed rate, drill diameter, point angle and clearance angle are the significant cutting parameters for affecting the burr thickness.

Table 6 shows the results of ANOVA for surface roughness, cutting speed, feed rate, drill diameter, point angle and clearance angle are the significant cutting parameters for affecting the surface roughness.

Table 7 shows the results of ANOVA for circularity deviation, cutting speed, point angle and clearance angle are the significant cutting parameters for affecting the circularity deviation.

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Table4: Results of ANOVA for burr height

Symbol	Cutting Parameters	DOF	SS	MS	F	
A	Cutting speed	2	0.00871	0.00435	36.25	significant
B	Feed rate	2	0.00292	0.00146	12.16	significant
C	Drill diameter	2	0.00218	0.00109	9.08	significant
D	Point angle	2	0.00684	0.00342	28.5	significant
E	Clearance angle	2	0.00140	0.00070	5.83	significant
Error		16	0.001926	0.00012		
Total		26	0.023976			

Significant, F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 5: Results of ANOVA for burr thickness

Symbol	Cutting Parameters	DOF	SS	MS	F	
A	Cutting speed	2	0.0066	0.0033	16.75	significant
B	Feed rate	2	0.0027	0.0013	6.598	significant
C	Drill diameter	2	0.0029	0.0015	7.614	significant
D	Point angle	2	0.00702	0.00351	17.766	significant
E	Clearance angle	2	0.0053	0.0027	13.705	significant
Error		16	0.00315	0.000197		
Total		26	0.02765			

Significant, F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 6: Results of ANOVA for surface roughness

Symbol	Cutting Parameters	DO F	SS	MS	F	
A	Cutting speed	2	2.96	1.48	3.797	significant
B	Feed rate	2	4.44	2.22	5.696	significant
C	Drill diameter	2	3.40	1.7	4.362	significant
D	Point angle	2	3.76	1.88	4.824	significant
E	Clearance angle	2	3.43	1.715	4.4	significant
Error		16	6.2353	0.3897		
Total		26	23.3653			

Significant, F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 7: Results of ANOVA for circularity deviation

Symbol	Cutting Parameters	DOF	SS	MS	F	
A	Cutting speed	2	0.00584	0.00292	3.74	significant
B	Feed rate	2	0.00177	0.00885	1.13	Insignificant
C	Drill diameter	2	0.00215	0.00107	1.37	Insignificant
D	Point angle	2	0.00579	0.00289	3.71	significant
E	Clearance angle	2	0.02307	0.01153	14.78	significant
Error		16	0.01248	0.00078		
Total		26	0.0511			

Significant, F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 8: Optimal values of individual machining characteristics

Machining characteristics	Optimal combination of parameters	Significant parameters(at 95% confidence level)	Predicted optimum value	Experimental value
Burr height (R_1)	A1B1C2D1E3	A,B,C,D,E	0.2618	0.2622
Burr thickness (R_2)	A3B1C1D1E1	A,B,C,D,E	0.1821	0.1843
Surface Roughness (R_3)	A3B3C3D2E3	A,B,C,D,E	3.7451	3.7378
Circularity deviation(R_4)	A3B1C1D1E1	A,D,E	0.0676	

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Confirmatory experiments were conducted for burr size, surface roughness and circularity deviation, corresponding their optimal setting of process parameters to validate the used approach, obtained the values of 0.2618mm, 0.1821mm, 3.7451μm, 0.0676mm for burr height, burr thickness, surface roughness and circularity deviation respectively. Predicted and experimental values of responses are depicted in Table 8.

5. ARTIFICIAL NEURAL NETWORK

Artificial neural systems are that physical cellular systems which acquire store and utilize experimental information. Powerful learning algorithm and self-organizing rule allow ANN to self-adapt as per the requirements in continually varying environment (adaptability property). The ANN architecture is a multilayer, feed forward back propagation architecture.

Multilayer perception (MLP) has an input layer, output layer and hidden layer. Input vector is incident on input layer and then to hidden layer and subsequently to final layer/output layer via weighted connections. Each neuron operates by taking the sum of its weighted inputs and passing the results through a non-linear activation function. A neural network is a machine that is designed to model the way in which the brain performs a particular task or function of interest.

To achieve good performance, they employ a massive interconnection of simple computing cells referred to as ‘Neurons’ or ‘processing units’. Hence a neural network viewed as an adaptive machine can be defined as a neural network is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use.

The experimental observations were incorporated into the ANN model. A feed forward neural network was developed to predict burr size, surface roughness and circularity deviation. As in future without undergoing the machining process able to get good machining data’s and its very useful ANN model for getting good optimum machining process.

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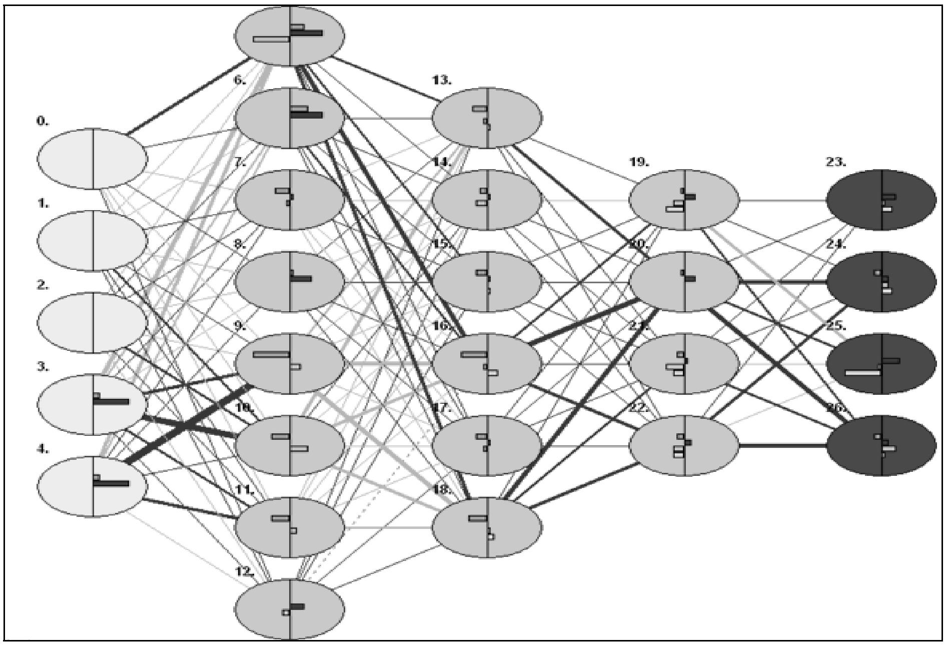

Figure 7: Artificial Neural Network diagram

Artificial Neural Network (ANN) Response Graphs:

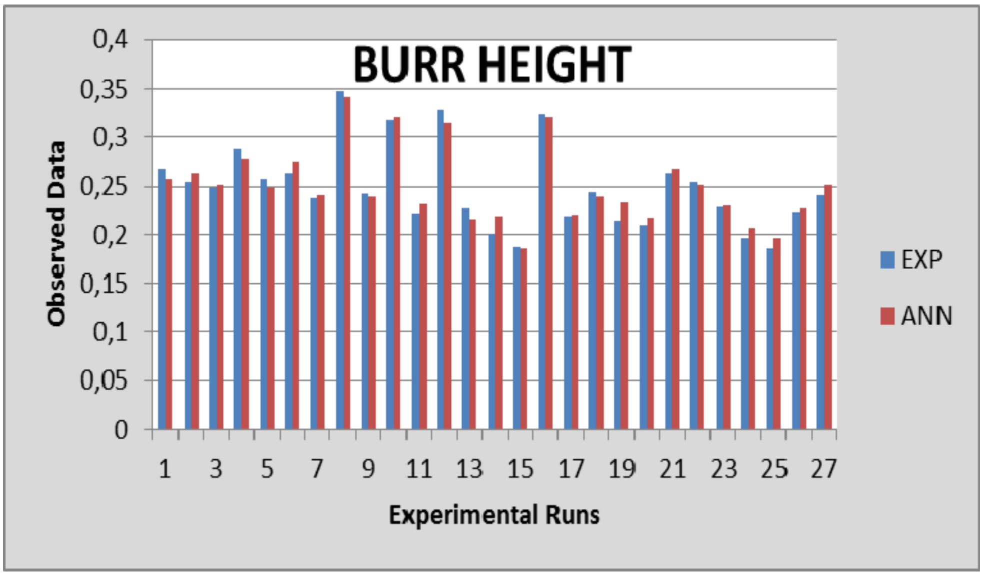

Figure 8: Response graph of burr height for Experimental Vs ANN

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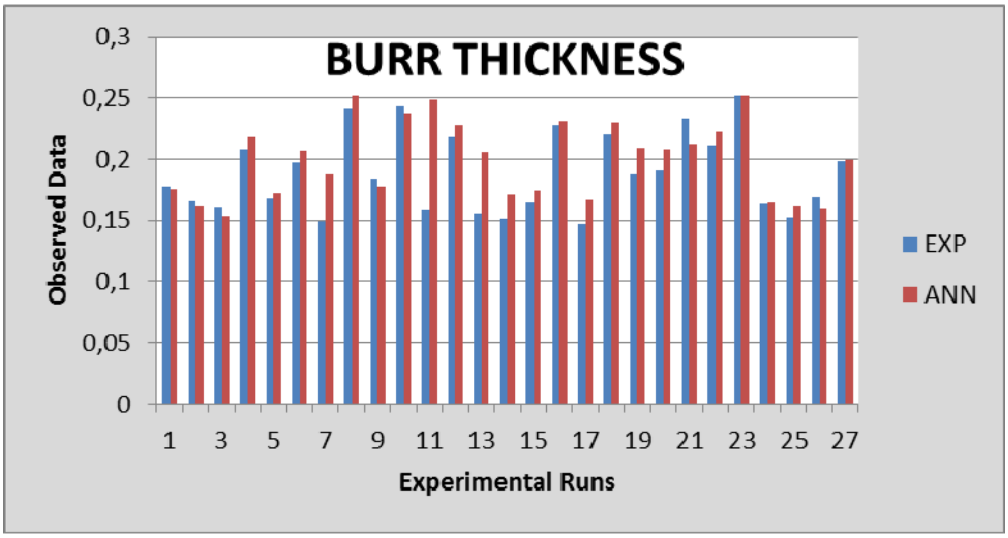

Figure 9: Response graph of burr thickness for Experimental Vs ANN

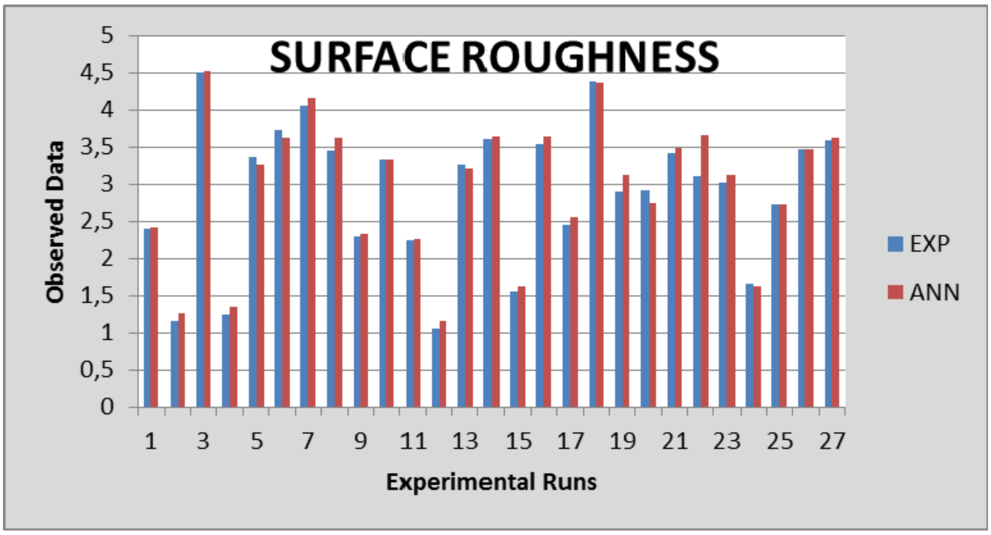

Figure 10: Response graph of surface roughness for Experimental Vs ANN

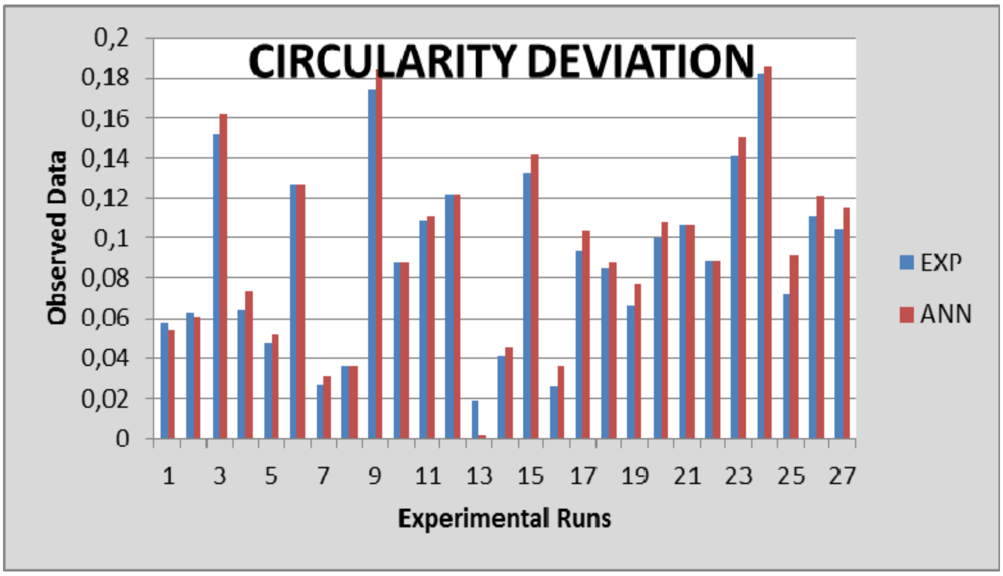

Figure 11: Response graph of circularity deviation for Experimental Vs ANN

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From ANN response graphs shown in figure no.8 to11, it is observed that except experiment no 13 in the case of circularity deviation, remaining experimental runs obtained less deviation for all responses. Increasing the number of nodes increases the computational cost and decreases the error. Good agreement was shown between the predictive model results and the experimental measurements.

6. CONCLUSIONS

The machining characteristics of Al6061 alloy have been studied. The primary machining characteristics such as burr size, surface roughness and circularity deviation were studied for drilling. The results obtained from the experiments as follows.

From S/N Ratio response graph, the combination of parameters having the values of 800 rpm, 0.3 mm/min ,10mm.118 degrees and 4 degrees obtained for cutting speed, feed rate drill diameter, point angle and clearance angle respectively for optimizing burr size, surface roughness and circularity deviation.

From S/N Ratio response table, feed rate, point angle, drill diameter, cutting speed and clearance angle has the order of influence on burr size, surface roughness and circularity deviation during drilling of Al6061 alloy.

From the results of ANOVA for cutting speed, feed rate, drill diameter, point angle and clearance angle, all parameters are significant for all responses except circularity deviation, for this cutting speed, drill geometry are more significant ,

From results of ANN, it is concluded that experiment No13 obtained relatively more error than remaining. The deviation between experimental values and prediction values are found in the range of 3 to 4%. Finally, concluded that increasing the number of nodes increases the computational cost and decreases the error. Good agreement was shown between the predictive model results and the experimental measurements.

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