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Experimental Studies on Effect of Machining Parameters on Burr Height during End Milling of Inconel 718 Super Alloys

Reddy Sreenivasulu[1], Shaik Hidayath Hussain[2], R.V. Vineeth RamaKrishna[3], R. Vijay Dasari[4], Pappala Suresh[5]

[1]Assistant Professor, Department of Mechanical Engineering, R.V.R & J.C.College of Engineering (Autonomous), Guntur, Andhra Pradesh, INDIA-522019

[2,3,4,5]UG Students,, Department of Mechanical Engineering, R.V.R & J.C.College of Engineering (Autonomous), Guntur, Andhra Pradesh, INDIA-522019

***corresponding author: Reddy Sreenivasulu[1]**

Assistant Professor, Department of Mechanical Engineering, R.V.R & J.C.College of Engineering (Autonomous), Guntur, Andhra Pradesh, INDIA-522019

Abstract: Machining possibilities during End milling of Inconel 718 super alloy is verified using Taguchi design of experiments. In that the response burr height is measured under the three machining conditions such as rotational speed, depth of cut and feed rate. To know the significance of input parameters on burr height ANOVA is conducted .The conclusions from S/N ratios and ANOVA reveals that feed rate are most significant factors to influence burr height in end milling.

Key words: Inconel 718, End milling, Taguchi method, ANOVA, Burr height

1. INTRODUCTION

CNC milling is most commonly used in industry and machine shops for machining parts to precise sizes and shapes with desire surface quality and higher productivity within less time and cost. High quality and productivity are two important but major criteria in several machining operations. End milling process operated by CNC is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. Nickel based super alloy, Inconel 718 is a very hard material (48 HRC). Inconel 718 is widely used in aircraft gas turbine, reciprocating engines, space vehicles (e.g., rocket engine parts), nuclear power plants, chemical application, high temperature fasteners, springs, rings and pulp and paper industry [5].The design of experiments was selected from Taguchi's L9 orthogonal array. Subsequent to the experiments, the effect of input parameters on burr height has been analyzed.

2. SELECTION OF MATERIAL AND TOOL

The workpiece material used in the present study is Inconel 718 super alloy with an average material hardness of 48 HRC. Microstructure of Inconel 718 consists of austenite FCC matrix and can be strengthened by solid solution strengthening (Mo, Cr) and precipitation hardening (Ti, Nb, Al) by forming intermetallic phases. The specification of cutting insert and tool holder is CNMG 1204 08-MS-KC5525 and PCLNR 2020K12, respectively. Chemical composition and mechanical properties are depicted in Table 1 and Table 2.

Table 1 Nominal Composition of Inconel 718

Elements	Ni	Cr	Cb	Mo	Ti	Al	Co	Si	Mn	Cu	C	P	Fe
% of weight	53.4	18.8	5.27	2.99	1.02	0.5	0.17	0.12	0.07	0.07	0.03	0.01	Bal

Table 2 Properties of nickel alloy 718

Physical Properties	Metric
Density	8.19 g/cc
Mechanical Properties	
Tensile Strength, Ultimate	1375 MPa
Tensile Strength, Yield	1100 MPa
Elongation at Break	25 %
Thermal Properties	
Specific Heat Capacity	0.435 J/g-°C
Thermal Conductivity	11.4 W/m-K
Melting Point	1260 - 1336 °C

3. 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 cutting characteristics of Inconel 718 material using K10 carbide end mill. Finally, confirmation test have been carried out to compare the predicted values with the experimental values to confirm its effectiveness in the analysis of surface roughness and chip thickness. 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 (DOF) of process parameters. Total degree of freedom (DOF) associated with three parameters is equal to 6 (3X2).The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters. There by, a L9 orthogonal array having degree of freedom equal to (9-1= 8) 8 has been considered.

In this study, the experiments are carried out on a CNC vertical machining center (KENT and ND Co. Ltd, Taiwan make) to perform 10mm slots on Inconel 718 super alloy work piece by K10 carbide, four flute end milling cutter as shown in Fig.1. Furthermore the cutting speed (A, rpm), the feed rate (B, mm/rev) and depth of cut (C, mm) are regulated in this experiment. Each experiment was conducted three times and the burrs are measured in mm using profile projector which are shown in Fig.2

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Fig.1a) Experimental setup (CNC Vertical Machining Center, KENT INDIA Co, Ltd, Taiwan)

Fig. 1b) K10 Carbide 4 Flute Milling cutter

4. BURR FORMATION

An unwanted projection of material formed during machining, termed as *burr* as a part size errors (Fig.3). Burr is plastically deformed material, generated on the part edge during cutting. Removal of burr is essential for any component to avoid damage of component after assembling due to abrasion, injuring workers while assembly and other related problems. So elimination of burr is mandatory which involves some cost, literally known as *deburring cost*.

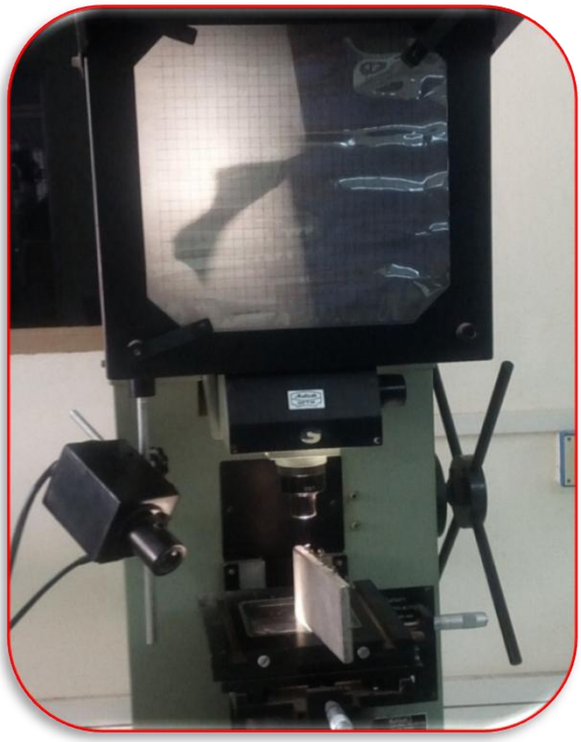

Fig. 2 Profile Projector for measuring Burr size

Fig. 3 Work Piece before deburring

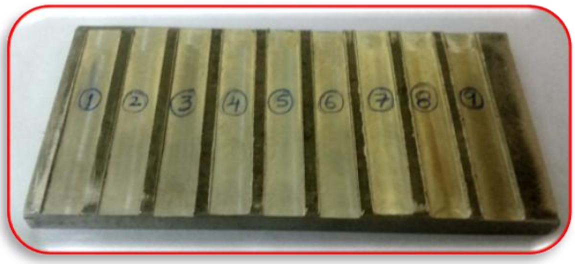

Fig. 4 Work Piece after deburring

The problem of deburring and edge quality (EQ) in the manufacturing environment is directly linked to the final use of the component [3.4]. The EQ is a function of the part design and is only necessary to edge finish within the design limits. To estimate cost of deburring and edge finishing operations certain standard procedure, human resources and extra machining time are required. If such a straight forward EQ standards are available, then find out expenses over post processing operations. This cost is non added value to the manufacturing cost, so must be minimize the burr to save money and to reduce manufacturing lead time. The measured data is depicted in Table 4.

Table 3. Factors and their Levels

LEVELS	Rotational speed, (A, rpm)	Depth of Cut, (B, mm)	Feed Rate (C, mm/rev)
1	1000	0.75	0.06
2	1500	1.00	0.09
3	2000	1.50	0.12

Table 4. Taguchi L_9 orthogonal array plan and measured responses

Rotational speed, (A, rpm)	Depth of Cut, (B, mm)	Feed Rate (C, mm/rev)	Burr Height (Bh, mm)	S/N Ratio
1000	0.75	0.06	5.75	-13.5186
1000	1.00	0.09	8.75	-15.7774
1000	1.50	0.12	5.90	-12.6709
1500	0.75	0.09	9.00	-16.3955
1500	1.00	0.12	3.50	-6.2549
1500	1.50	0.6	8.00	-13.3520
2000	0.75	0.12	2.50	-3.8974
2000	1.00	0.06	5.50	-10.0687
2000	1.50	0.09	6.50	-11.5252

5. RESULTS AND DISCUSSION

The data obtained from experimentation is analyzed for hypothesis testing, whether considered factors for conducting experiments as per Taguchi design method are influenced or not over the output responses statistical methods are required. To identify this ANOVA is conducted using Minitab@18 design of experiments software. Main effects, interaction effect plots are obtained, which is helpful to discuss about influence of input factor on output parameters considered during end milling. Burr height is minimum requirement, so smaller the better case considered for S/N ratio under the Taguchi method and obtained A2B3C1 order of preference of level of input parameters to attained optimum values of responses. The signal-to-noise (S/N) ratio for each level of process parameters are computed. The optimum setting of the process parameters contributes the minimization of the effect of noise. It means that the level of process parameters with the highest S/N ratio corresponds to the optimum level of process parameters. For smaller the better case, S/N ratio is given by

$$(S/N)_{LB} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^2)\right]$$

Where, y_i = experimental value in the i th test

y_0 = target value and

n = number of replications

Table 5. Response for Signal to Noise Ratios

Smaller is better

Level	ROTATIONAL SPEED (A) rpm	DEPTH OF CUT (B) mm	FEED RATE (C) mm/rev
1	-13.989	-11.270	-11.794
2	-12.001	-10.700	-14.566
3	-8.497	-12.516	-7.608
Delta	5.492	1.816	6.958
Rank	2	3	1

Table 6. Response for Means

Level	ROTATIONAL SPEED (A) rpm	DEPTH OF CUT (B) mm	FEED RATE (C) mm/rev
1	4.177	3.563	3.000
2	3.350	2.849	4.310
3	1.929	3.043	2.107
Delta	2.248	0.714	2.203
Rank	1	3	2

Table 7. Analysis of Variance (ANOVA) for BURR HEIGHT

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	35.8135	5.1162	1.42	0.571
ROTATIONAL SPEED (A) rpm	2	6.1923	3.0961	0.86	0.607
DEPTH OF CUT (B) mm	2	0.3723	0.1861	0.05	0.952
FEED RATE (C) mm/rev	3	26.0340	8.6780	2.41	0.435
Error	1	3.6038	3.6038		
Total	8	39.4172			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.89835	90.86%	26.86%	91.52%

6.1 Main effect and Interaction effect plots for responses

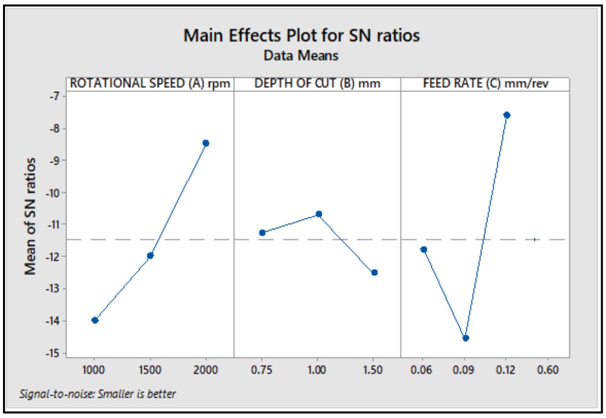

Fig. 5 Main effect plot for S/N Ratio

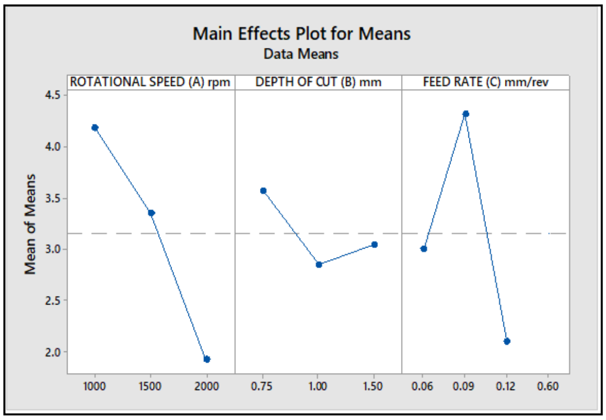

Fig. 6 Main effect plot for means

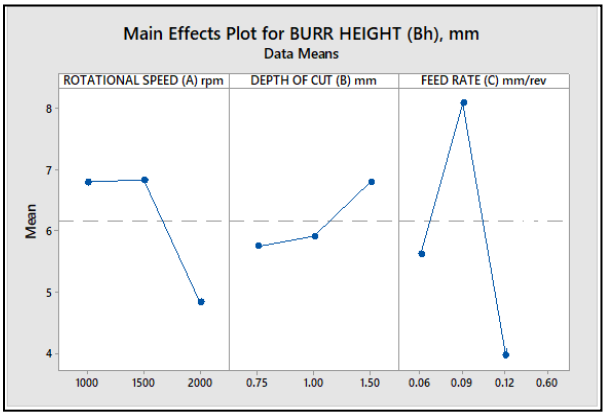

Fig. 7 Main effect plot for Burr height

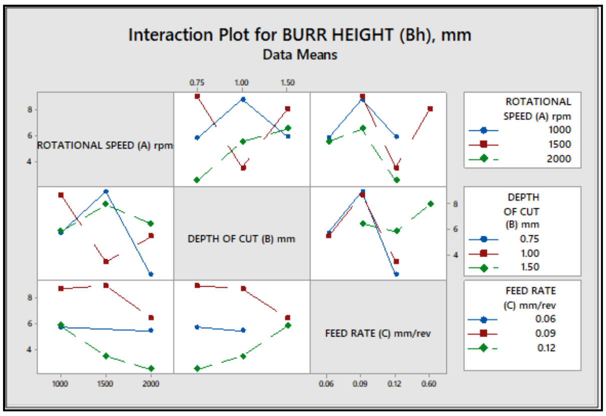

Fig. 8 Interaction plot for Burr height

The effects of input parameters on data means of responses is observed from Fig. 5 reveals that all input parameters under third level influence more on output responses i.e. increase of rotational speed, feed rate and depth of cut causes optimum values of surface roughness and burr size simultaneously. From Fig.6 divulges that lower of rotational speed and depth of cut, medium range of feed rate effect on means of responses. The main effect plot of burr height is affected by the medium range of rotational speed and feed rate simultaneously which is observed from Fig. 7. From Fig.8 observations reveal that higher values of rotational speed and feed rates more significant than depth of cut. After finding the most significant factors, confirmation test is conducted and obtained good agreement with experimental values. Also it is identified from ANOVA results R-sq and R-sq (pred) values are more than 90%, shows that hypothesis is good agreement with selection and conducting experimental method.

CONCLUSIONS

From the results and discussions, the following conclusion are drawn.

- The burr height is influenced by combined effect of rotational speed and feed rate. From confirmation experiment, 13.26% improvement towards burr height by adopting Taguchi method is observed.

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