Optimization of Surface Roughness for milling of Zirconia Ceramic Material

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Abstract: *In this study, taguchi method was utilized for optimization of surface roughness in milling of zirconia ceramic material. Experiments were performed by varying the cutting speed, feed rate, and depth of cut which were the control factors. An orthogonal array L9, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were employed to study the performance characteristics in milling of zirconia ceramic material using tungsten carbide tool. The investigation revealed that the depth of cut was the most influential parameter followed by cutting speed.*

Keywords: surface roughness, taguchi, cutting speed, milling, feed rate.

1. INTRODUCTION

Milling is a machining process which is used in various manufacturing, dental, aerospace, automotive, industries and is used to create surfaces with high tolerances which may be used for the purpose of mating with other components. Surface roughness is an important feature of a machining process as the part when mates with other part may result in friction, wearing, etc. Surface roughness for a dental material is very important as the tooth has to mate with other teeth properly or else it may result in inconvenience caused to human body. No manufacturer provides parameters for achieving the minimum surface roughness and it has to be found by trial and error method. Julie Z et al. [1] had optimized the surface roughness using taguchi method in an end milling operation concluding that taguchi technique successfully optimized the surface roughness. Reddy Sreenivasulu [2] used taguchi technique and artificial neural network to optimize the surface roughness and delamination damage of GFRP composite material . Cutting speed, feed rate and depth of cut were used as input parameters out of which cutting speed and depth of cut was found to be more influencing the surface roughness and delamination. Eyup Bagci et al. [3] used feed rate, cutting speed and depth of cut as milling parameters for face milling of cobalt based alloy. Effectiveness of taguchi method was illustrated by confirmation test with optimal level of parameters. M. Subramanian et al.[4] adopted response surface methodology (RSM) for modeling, analysis and optimization of surface roughness of Al7075-T6 material in end milling process. The model developed by the researchers was able to efficiently compute the surface roughness of the material. Mukesh Kumar et al. [5] used design of experiments for modeling and analysis of the influence of input parameters on surface roughness. RSM technique was further used for its optimization. Saurin Sheth et al. [6] investigated the effect of spindle speed, feed and depth of cut on surface roughness and flatness during face milling of wrought cast steel. The investigation concluded that the speed and feed has more significance on surface roughness and flatness. K. Palanikumar et al. [7] used RSM technique for optimization of surface roughness during turning of Aluminium – silicon carbide reinforced metal matrix (Al/SiC-MMC) composite materials and found feed rate to have greater influence on surface roughness. Hasan Oktem et al. [8] used Taguchi orthogonal arrays, signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) to find the optimal levels of input parameters and their effect on surface roughness. They improved the surface roughness by 5.1%. Nilrudra Mandal et al. [9] performed experiments based on central composite design for optimization of surface roughness during high speed machining of AISI4340 steel. They developed mathematical model using second order regression analysis. Cutting depth compensation method and feed rate optimization method to improve the flatness in face milling was given by Bruce L. Tai et al. [10] based on 3-D holographic laser metrology. S. Hossein Cheraghi et al.[11] formulated nonlinear optimization problem with linear objective function and non linear constraints for optimization of straightness and flatness. Feng Jiang et al. [12] optimized surface roughness for end milling under different lubrication conditions and concluded that surface roughness is influenced by feed per tooth and axial depth of cut. Gerardo Beruvides et al. [13] modeled and optimized surface roughness for micro milling process using multi objective genetic algorithm.

2. EXPERIMENT DETAIL

The setup of milling experiment is shown in Fig. 1 which was conducted on CNC HAAS Vf-1 model three-axis CNC milling machine equipped with a maximum spindle speed of 10000 rpm and a 14.9-kW drive motor. Work piece used was in the shape of block measuring 72-42-14 mm made up of Zirconia ceramic. Flat end tungsten carbide tool of 3mm diameter, 12 mm flank length and 30^0 helix angle was used as shown in Fig.2.

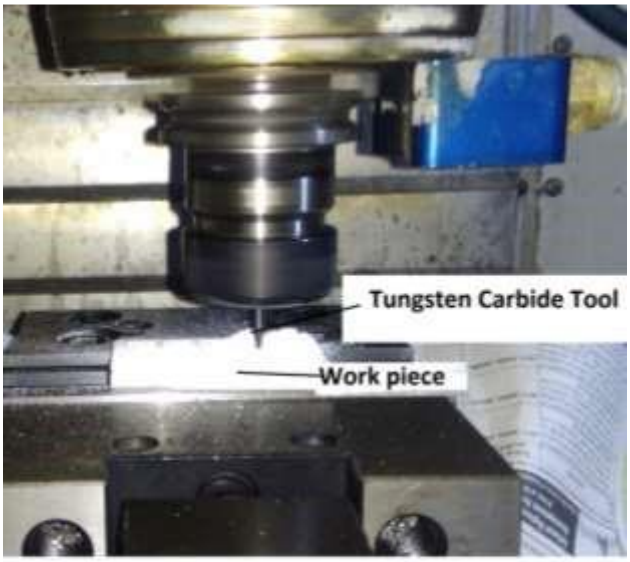

Fig. 1. Milling setup

Fig. 2. Tungsten carbide tool

3. SURFACE ROUGHNESS MEASUREMENT

The surface roughness of the work piece was measured by using Taylor Hobson Talysurf 4 surface roughness tester which is shown in Fig. 3. The result of the surface roughness is provided digitally on computer.

Fig. 3. Surface Roughness Measurement

4. TAGUCHI DESIGN

Actual experimental design procedures involve a lot of experiments which requires a lot of time and cost. The experiment increases with increase in the number of input parameters. Taguchi methods has been widely used by researchers [1-3] in engineering analysis which consist of defined number of experiments based on the number of input parameters and results in saving of time and cost. The input parameters selected with their levels are given in Table 1. For three input parameters at three different levels taguchi orthogonal array L9 is used. Experiments were performed in random order. Table 2 shows the L9 array with the measured surface roughness and S/N ratio. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic; lower is better (LB), nominal is best (NB), or higher is better (HB) [3]. Minimum surface roughness is required so lower is better characteristic is selected for the study which is given by Eq. (1)

Lower is better $\frac{S}{N} = -10\log\frac{1}{n}(\sum x^2)$ (1)

where n = number of observations

x = is the measuring data

Parameters	Units	Level 1	Level 2	Level 3
Cutting Speed (A)	rpm	7500	8500	9500
Feed (B)	mm/min	75	105	135

Depth of Cut (C)	mm	0.4	0.8	1.2

Table 1 Input parameters and their levels

Exp. no	Speed	Feed	Depth of Cut	Ra	S/N Ratio
1	7500	75	0.4	0.358	8.922339
2	7500	105	0.8	0.47	6.558043
3	7500	135	1.2	0.4	7.9588
4	8500	75	0.8	0.323	9.81595
5	8500	105	1.2	0.393	8.112149
6	8500	135	0.4	0.247	12.14606
7	9500	75	1.2	0.372	8.589141
8	9500	105	0.4	0.306	10.28557
9	9500	135	0.8	0.4	7.9588

Table 2 L9 orthogonal array with surface roughness and S/N ratio

5. ANALYSIS OF DATA

5.1 S/N RATIO

Effect of the input parameters on surface roughness was analyzed with S/N response table shown in Table 3. The table shows the optimal level of input parameter for optimized surface roughness. The optimal values are also shown in Fig. 4. According to the graph the best level of input parameters was found to be factor A at Level 2 , factor B at Level 3 and factor C at Level 1 that is Cutting speed at 8500 rpm, feed rate at 135 mm/min and depth of cut at 0.4 mm.

Level	Speed	Feed	Depth of Cut
1	7.813	9.109	**10.451**
2	**10.025**	8.319	8.111
3	8.945	**9.355**	8.22
Delta	2.212	1.036	2.34
Rank	2	3	1

Table 3 S/N response table for surface roughness

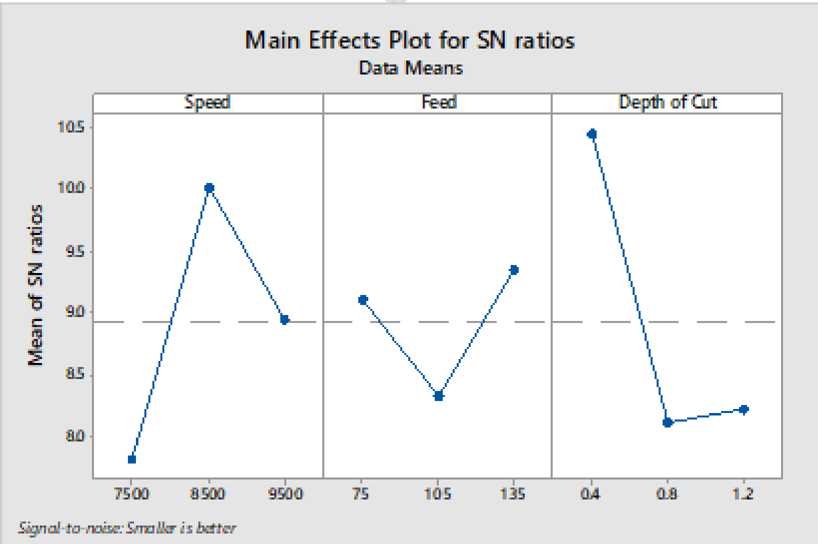

Fig. 4. Effect on input parameters on S/N ratio

5.2 ANOVA

ANOVA is a method which is used to determine the individual interactions of all of the control factors in the test design [14]. In this study, ANOVA was used to analyze the effects of input parameters on surface roughness. The ANOVA results for the surface roughness shown in Table 4. The significance of control factors in ANOVA is determined by comparing the F values of each control factor. According to Table 4, the percent contributions of the A, B and C factors on the surface roughness were found to be 35.00%, 9.43% and 48.04% respectively. Thus, the most important factor affecting the surface roughness was depth of cut followed by cutting speed which is similar to result given by [2] and [6].

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	%C
Cutting Speed	2	0.011772	0.005886	4.75	**35.00**
Feed	2	0.003153	0.001576	1.27	9.43
Depth of Cut	2	0.016092	0.008046	6.49	**48.04**
Error	2	0.002481	0.00124		7.53
Total	8	0.033498			

Table 4 Anova results for surface roughness

5.3 OPTIMUM SURFACE ROUGHNESS

The optimum surface roughness of the work piece was predicted by using the taguchi optimization technique. For its prediction taguchi equation Eq 2. was used.

$$Ra_{opt} = T_{Ra} + (A_2 - T_{Ra}) + (B_3 - T_{Ra}) + (C_1 - T_{Ra}) \quad (2)$$

Where T_{Ra} – average of all roughness values

A_2 B_3 C_1 – represent the optimum level average values of surface roughness

5.4 Confirmation test

After finding the optimum level of input parameters for cutting speed, feed and depth of cut it was necessary to conduct validation of these results. For this purpose machine settings were set on optimum levels and again experiments were conducted and output was measured. The details are given in the Table 5. From Table 5 it can be seen that the error between the actual and predicted values is1.61%.

Response	**Factor A**	**Factor B**	**Factor C**	**Output Predicted**	**Experiment value**	**Error %**
Surface Roughness	8500	135	0.4	0.245	0.247	1.62

Table 5 Predicted and experiment value at optimum level

6. CONCLUSION

In this paper taguchi optimization technique was utilized for optimizing surface roughness during milling of zirconia ceramic material. Based on above investigation following conclusions can be made.

- The optimum level of parameters A2 B3C1 was determined by the response table from S/N ratio.
- Surface roughness was chiefly influenced by depth of cut (48.04%) followed by cutting speed (35.00%).
- Error of only1.62% was found between predicted and experimented value.

Based on the above conclusions it can be seen that taguchi optimization technique was successful in optimizing the parameters of machining and also helped in reduction of costs by saving time and number of experiments.

7. REFERENCES

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