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Optimization of End Milling Parameters on Surface Roughness of Die Steel HCHCr by Taguchi Method

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Abstract: ***This paper outlines the Taguchi Optimization methodology, which is applied to optimize cutting parameters in end milling when machining Die steel (HCHCr D3). The milling parameters evaluated are cutting speed, feed rate and Depth of cut. An orthogonal Array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to analyze the effect of experiment (DOE), Mathematical model is generated by regression analysis..Finally effect of process parameter on surface roughness (Ra) in end milling studied and optimum solution is carried out. The study shows that the taguchi method is suitable to solve the surface quality problem with minimum number of trial.***

Keywords: Optimization, End Milling, Taguchi Method, Surface Roughness, orthogonal Array, ANOVA

1. Introduction

In present time the technology of CNC vertical milling machine has been improved significantly to meet the advance requirements in various manufacturing fields, especially in the precision metal cutting industry. In die making industry End milling is the most important operation. [1]This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on Surface roughnes in end milling. The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish.[1,8,10]

1.1 Surface Roughness and Measurement

Quality is an important factor in the production of dies.[2]The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, and creep life. Surface roughness also affects several functional attributes of parts, such as wearing, heat transmission, ability of holding a lubricant, coating, or resisting fatigue. [3] Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality. Several factors influence the final surface roughness in end milling operation [3,4]. Factors such as spindle speed, feed rate, and depth of cut that control the cutting operation can be setup in advance. However, factors such as tool geometry, tool wear, and chip formation, or the material properties of both tool and workpiece are uncontrolled [8].

There are several way to describe surface roughness.One of them is average roughness which is offen quoted as Ra symbol. Ra is defined as the arithmetic value of the departure of the profile from the center-line along sampling.[5]

This experimental investigation outlines the Taguchi optimization methodology, which is applied to optimize Ra value in end milling operation. The experiment is conducted on HCHCr (D3) the processing of the job is done by Solid Carbid TH coated end-mill tool under finishing conditions. [7]The machining parameters evaluated are cutting speed, feed rate and depth of cut. The experiments are conducted by using Taguchi L**9** orthogonal array as suggested by Taguchi. Signal-to- Noise (S/N) ratio and Analysis of Variance (ANOVA) is employed to analyse the effect of milling parameters on Surface Finish (Ra value).

2. Experimental Details

2.1 Design of Experiment

DOE is a powerful analysis tool for modelling and analysing the influence of control factors on performance output. The traditional experimental design is difficult to be used especially when dealing with large number of experiments and when the number of machining parameter is increasing [8]. Taguchi method, which is developed by Dr. Genichi Taguchi, is introduced as an experimental technique which provides the reduction of experimental number by using orthogonal arrays and minimizing the effects out of control factors [8]. Taguchi is a method which includes a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analysis data in order to obtain the information about behaviour of the given process [1, 10, and 11]. This technique has been applied in the manufacturing processes to solve the most confusing problems especially to observe the degree of influence of the control factors and in the determination of optimal set of conditions [1]. The Taguchi method could decrease the experimental or product cycle time, reduce the cost while increasing the profit and determines the significant factors in a shorter time period as it can ensure the quality in the design phase [8,12].

The first step in Taguchi's parameter design is selecting the proper orthogonal array (OA) according to the controllable factors (parameters). Then, experiments are run according to the OA set earlier and the experimental data are analyzed to identify the optimum condition. Once the optimum conditions are identified, then confirmation runs are conducted with the identified optimum levels of all the parameters [12]. The use of parameter design in Taguchi's technique is an engineering method of focusing on determining the parameter settings producing the best levels of a quality characteristic with minimum variation for a product or process.[10]

In the Taguchi method the term signal represent the desirable value (mean) for the output characteristic and the term noise represent the undesirable value for the output characteristic.[4]Taguchi uses the S/N ratios to measure the quality characteristic deviating from the desired value. there are several S/N ratios available depending on types of characteristics.[6] Smaller is better S/N ratio used here because the quality characteristic is Surface Roughness (Ra).[9]

2.2 Working Machine

For the experiments HASS CONTROL CNC Machine is used

Figure 1: Working Machine HASS End Mill

High performance HASS END MILL is used which having working space X,Y,Z movements being 600×460×570mm variable spindle speed. Optimum 8000 rpm main spindle power 14.7 kw having table size 700 ×500 mm was employed to perform experiments.

2.3 Workpiece material

The experiment is carried out on HCHCr (AISI D3)die steel material (65 x 60 x 20 mm) 9 blocks Whose compositions are as follows.

Table 1: Chemical composition of die steel HCHCr(AISID-3)

C	Si	Cr	Mn	Ni	HRC
2.10%	0.30%	11.50%	0.40%	0.31%	60-62

2.4 End Mill Cutter

For this experimentation dia 10mm 4 flute flat solid carbide (TH coated) cutter is used. [6]

2.5 Surface Roughness Tester

Taylor Hobson Surface tester is used for taking Ra values. It contains a prob which is movable. By some force this prob is moved on surface of workpies. It has ±0.03µm accuracy.

Figure 2: Surface roughness tester

3. Experimental Conditions

The experimental series is carried out on HASS End mill machine (IGTR-Aurangabad). OVAT analysis is done before experimentation to decide the three levels of each input parameter (i.e. cutting speed, feed & depth of cut).

3.1 Process parameters & Units

Table shows the parameters and their units

Table 2: Parameters & units

Process parameters	*Units*
Cutting speed	rpm
Feed Rate	mm/min
Depth of cut	mm

After the OVAT analysis we defined 3 levels for each parameter

Table 3: Selected Process Parameter levels

Process parameters/levels	*Level1*	*Level2*	*Level3*	*Units*
Cutting speed	2800	3000	3200	rpm
Feed Rate	250	300	350	mm/min
Depth of cut	0.02	0.04	0.06	mm

Table 4: L9 Orthogonal Array by Minitab 14

Experiment no.	*Cutting speed (RPM)*	*Feed Rate (mm/min)*	*Depth of Cut (mm)*
1	2800	250	0.02
2	2800	300	0.04
3	2800	350	0.06
4	3000	250	0.04
5	3000	300	0.06
6	3000	350	0.02
7	3200	250	0.06
8	3200	300	0.02
9	3200	350	0.04

4. Result and Analysis

After all 9 experiments are carried out a table is generated by Minitab 14 which contains Ra value and S/n ratio.

Table 5: Ra and S/N ratio Values

Experimen no.	Cutting speed (RPM	Feed Rat (mm/min	Depth of Cut (mm)	Ra Value	S/N Ratic
1	2800	250	0.02	0.39	7.4513
2	2800	300	0.04	0.54	4.5091
3	2800	350	0.06	0.62	4.2450
4	3000	250	0.04	0.30	8.5460
5	3000	300	0.06	0.50	5.3363
6	3000	350	0.02	0.62	4.7177
7	3200	250	0.06	0.25	10.0189
8	3200	300	0.02	0.38	8.4194
9	3200	350	0.04	0.51	5.2298

4.1 Analysis of Data

a) S/N Ratio analysis

Table 6: Response Table for Signal to Noise Ratio-Small is better (Ra Value)

Level	CS	feed	Doc
1	5.894	10.226	6.912
2	6.877	6.592	7.219
3	8.769	4.718	7.405
Delta	2.870	5.508	0.493
Rank	2	1	3

Table 7: Response Table for Means

Level	CS	feed	Doc
1	0.5167	0.3133	0.4633
2	0.4733	0.4733	0.4500
3	0.3800	0.5833	0.4567
Delta	0.1367	0.2700	0.0133
Rank	2	1	3

Above tables clearly indicates the optimal condition of process parameters. Optimal value levels for better surface finish Ra are at cutting speed 3200 rpm, feed is at 250mm/min and depth of cut is 0.04mm.The delta is the highest minus the lowest average for each factor. Minitab assigns rank based on Delta value. Rank one to the highest Delta value, rank two to the second highest and so on. From ANOVA we can say that most affecting factor is feed and least is Depth of cut.

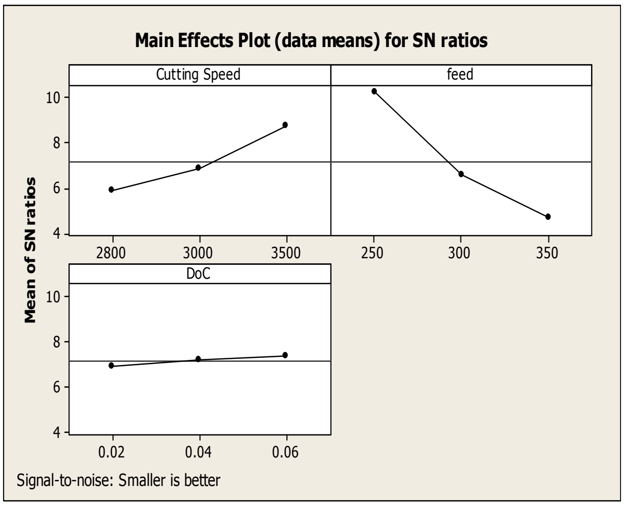

Figure 3: Effect of process parameter on S/N Ratios

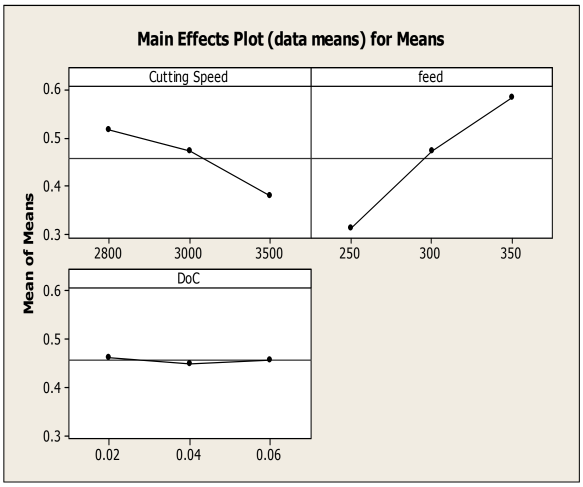

Figure 4: Effect of process parameters on Mean

4.2 Analysis Of Variance (ANOVA)

The analysis of the experiment data is carried out by using the software MINITAB 14. Analysis of variance is performed on experimental data. Table 9 shows the result of the ANOVA with the surface roughness. The last column of the table indicates p_value for the individual control factors. The Anova Table 7 indicates that the cutting speed (p=0.067), feed (p=0.019) and depth of cut (p=0.846). When p-value is below 0.05 we may say that the factor is affecting on response parameter. And if there are more values under 0.05 then the lowest value indicates the most significant factor.

Table 8: Analysis Of Variance for S/N Ratio, Using Adjusted SS for tests

Source	DF	Seq ss	Adj SS	Adj MS	F	P
speed	2	18.389	18.3893	9.1947	13.91	0.067
feed	2	68.4039	68.4039	34.2019	51.74	0.019
DOC	2	0.2403	0.2403	0.1202	0.18	0.846
Error	2	1.3221	1.3221	0.6610		
Total	8	88.3556				

S = 0.8130 R-Sq = 98.5% R-Sq(adj) = 94.0%

Table 9: Analysis of variance For Ra, Using SS for test

Source	*DF*	*Seq ss*	*Adj SS*	*Adj MS*	*F*	*P*
speed	2	12.7685	12.7685	6.3843	8.71	0.103
feed	2	47.0568	47.0568	23.5284	32.09	0.030
DOC	2	0.3720	0.3720	0.1860	0.25	0.798
Error	2	1.4664	1.4664	0.7332		
Total	8	61.6637				

S = 0.8563 R-Sq = 97.6% R-Sq(adj) = 90.5%

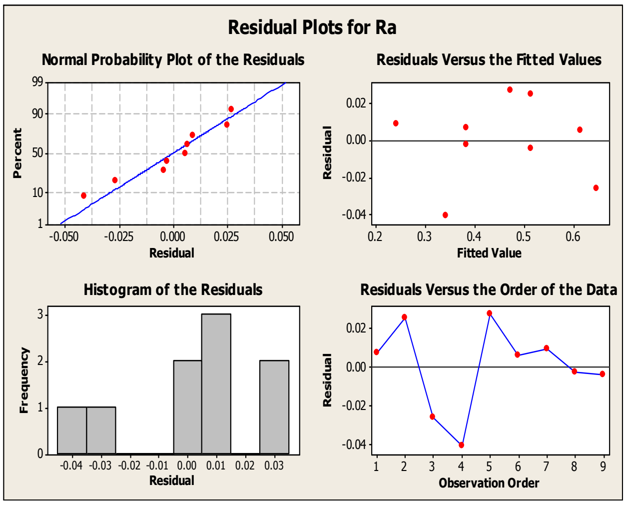

Figure 5: Residual Plots for SN Ratio of Ra

4.3 Regression Analysis

Mathematical Model for process parameter such as cutting speed, feed, depth of cut were obtained from regression analysis using MINITAB 14 statistical software to predict surface Roughness.

4.4 Taguchi predicted value

From graphs, obtained after residual is clear that at high SN ratio low Ra value can be obtained. After selecting cutting speed at 3200 rpm, feed at 250mm/min and depth of cut at 0.04mm Predicted value by Taguchi as follows:

S/N ratio	Mean
11.8528	0.2316

4.5 Confirmation Test

At Cutting speed 3200 rpm, feed at 250 mm/min, DOC at 0.04mm trials were taken for confirmation test. By this validation of mathematical model for Ra value made by regression Analysis is validated. In this experimental result in Table 3 and predicted values were compared and it is observed that % error is varying in between 0.95% to 4.77%. Hence it is concluded that model is valid.

Table 9: Confirmation Tests for Predicted value by Taguchi Method

Sr. No	*Predicted Ra Mean Value*	*Trials*		*Ra mean value*	*% Error*
		1	2		
1	0.2336	0.2398	0.2410	02404	2.91%

The result are shown in above table and it is observed that average Ra is 0.2404 µm and average S/N ratio 11.8528 which falls within predicted 80% Confidence Interval.

5. Conclusions

1) It is observed that Cutting speed and Feed has significant effect on Surface Roughness.
2) Feed is the most significant parameter on surface roughness.
3) Experiment shows that in end milling process there is lest effect of Depth of cut on surface roughness of product.
4) Also prediction made by Regression Analysis is in good agreement with Confirmation Tests.
5) Hence we can say that for low roughness value higher cutting speed and low feed rate is required.
6) Optimized level of parameters for End Milling Operation: Cutting Speed 3200 rpm, feed 250 mm/min and Depth of cut is 0.04 mm.

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