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SURFACE ROUGHNESS OPTIMIZATION OF HCHCR STEEL WITH PVD COATED END MILLING CUTTERS UNDER THE INFLUENCE OF MOS_2 BY RSM ANALYSIS.

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Abstract.

In this research work investigation is carried out on CNC milling machine for the machining of HCHCr steel. The performance of PVD coated End milling cutters of different materials using solid lubricant is evaluated for optimization of surface roughness. Cutting conditions for optimum coating thickness are identified. The regression analysis is used to create mathematical model for surface roughness in terms of cutting parameters such as speed, feed, depth of cut and percentage concentration of MoS_2 mixed with SAE-20 base oil. The experimentation is performed using full factorial method of design of experiments to collect the surface roughness data and the Response Surface Methodology is used for optimization. The surface roughness t optimum parameter setting is 1.39 µm for PVD coating of AlCrN with 4 micron thickness. The composite desirability for 2.5 and 4 micron coating thickness of various coating materials is 0.88 and 0.94 respectively. The local solution for 2.5 micron PVD coating thickness is V=56.52 m/min, F= 0.33 mm/rev, D=0.25 mm and %C=0.2 by wt for optimum surface roughness and for 4 micron PVD coating thickness is V and F are the same whereas D=0.254 mm and %C=0.4 by wt for optimum surface roughness.

Keywords: End Milling, Surface Roughness, PVD Coating, RSM, MoS2, HCHCr.

1. INTRODUCTION

Milling is widely employed material removal process for different materials. Machining creates high friction between tool and work piece resulting high temperature which impairs the dimensional accuracy and surface quality. The effective control of heat generated at the cutting zone is essential to ensure the good surface quality in machining.

Dry machining is ecologically desirable and it will be considered necessary for manufacturing enterprise in near future. Industries will be compelled to consider dry machining to enforce environmental protection for occupational safety and health regulations. The advantages of dry machining include: non pollution of atmosphere, no residue on floor which will be reflected in reduced disposal and cleaning costs, no danger to health. Moreover, it offers cost reduction in machining. In milling operation there are large numbers of machining parameters which affect the surface roughness during machining. The machining parameters considered for experimentation are speed, feed, depth of cut, percentage of solid lubricant MoS_2 mixed with SAE-20 base oil.

2. EXPERIMENTATION

The experiments are performed on CNC milling machine as per the design of experiments. The CNC milling machine was Jyoti make VMC 850 model. The design of experiment is based on the full factorial method with two levels of input parameters; there are four midpoint experiments of each parameter which makes total number of experiments as 20 for each coating thickness and coating material. The chemical composition of work piece material is given in table 1.

Table 1. Chemical Composition of HCHCr

Composition	Content	Range
%C	1.68	1.50 - 1.70
%Mn	0.29	0.25 - 0.55
%Cr	11.16	11.00- 13.00

Table 2. Input parameters range

Sr. No.	V	F	D	%C	Symbol
Min.	37.68	0.33	0.25	0.20	-1
Middle	47.10	0.36	0.30	0.30	0
Max.	56.52	0.40	0.35	0.40	+1
Unit	m/min	mm//rev	mm	by wt	--

%Ni	0.17	--
%Mo	0.11	0.80 max
%S	0.021	0.35 max
%P	0.018	0.35 max
%Si	0.30	0.10 - 0.35
%V	0.05	0.80 max
%W	0.02	--

The parameters of given sample confirms to "TAC – 21/X160Cr12 grade as per IS 1570 (Part 6) – 1996. Equivalent to HCHCr D-2 grade (Desi. X160 Cr12 as per IS 1762 (Part - 1): 1974).The actual range of values of input parameters are given in table 2.

Table 3. Design of Experiments

EXPT. NO.	INPUT PARAMETERS			
	V	F	D	%C
1	37.68	0.33	0.25	0.2
2	56.52	0.33	0. 25	0.2
3	37.68	0.4	0. 25	0.2
4	56.52	0.4	0. 25	0.2
5	37.68	0.33	0.35	0.2
6	56.52	0.33	0.35	0.2
7	37.68	0.4	0.35	0.2
8	56.52	0.4	0.35	0.2
9	37.68	0.33	0. 25	0.4
10	56.52	0.33	0. 25	0.4
11	37.68	0.4	0. 25	0.4
12	56.52	0.4	0. 25	0.4
13	37.68	0.33	0.35	0.4
14	56.52	0.33	0.35	0.4
15	37.68	0.4	0.35	0.4
16	56.52	0.4	0.35	0.4
17	47.1	0.36	0.3	0.3
18	47.1	0.36	0.3	0.3
19	47.1	0.36	0.3	0.3
20	47.1	0.36	0.3	0.3

Table 4. Minimum and Maximum Surface roughness for different coating materials for 2.5 micron PVD coating thickness.

Coating Material	Surface Roughness (µm)	
	Minimum	Maximum
TiCN	1.43	7.64
HELICA	1.50	4.62
AlCrN	1.41	5.65
TiAlN	1.36	6.08
TiN	1.42	4.11

Table 5. Minimum and maximum values of Surface roughness for different coating materials of 4 micron PVD coating thickness.

Coating Material	Surface Roughness (µm)	
	Minimum	Maximum
TiCN	1.58	4.10
HELICA	1.22	4.48
AlCrN	1.36	4.83
TiAlN	1.40	4.74
TiN	1.38	4.62

In this analysis the cutting speed V (X_1), feed rate F (X_2), depth of cut D (X_3) and percentage concentration of solid lubricant MoS_2 mixed with base oil SAE-20 %C (X_4) are the input machining parameters. The details of design of experiments are given in table 3.

The Surface Roughness was measured with the help of Surface Roughness Tester, mitutoyo make SJ-201. The measured values for each set of experiment of TiCN, HELICA, AlCrN, TiAlN and TiN PVD coating thickness of 2.5 and 4 micron thickness are represented in terms of their maximum and minimum limits as given in table 4 and 5.

3. FORMULATION OF MATHEMATICAL MODEL

Regression analysis is a statistical process for estimating the relationships among variables. It focus on the relationship between a dependent variable and one or more independent variables . Regression analysis is widely used for prediction and forecasting. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. The mathematical model is formulated with the help of measured values by using MINITAB 16 software. The regression coefficients for surface roughness model are evaluated considering interactions.

$$Ra\ (2.5\ \mu m) = 669.966-13.2867X_1 - 1834.68X_2 - 2176.93X_3 - 2384.09X_4 + 36.901X_1X_2 + 43.488X_1X_3 + 49.2177X_1X_4 + 6038.57X_2X_3 + 6650.36X_2X_4 + 8196X_3X_4 - 122.005X_1X_2X_3 - 138.838X_1X_2X_4 - 170.765X_1X_3X_4 - 22950X_2X_3X_4 + 483.773X_1X_2X_3X_4 \quad (1)$$

$$Ra\ (4\ \mu m) = -155.528 - +3.37663X_1 + 442.095X_2 + 489.371X_3 + 183.182X_4 - 9.32666X_1X_2 - 10.2335X_1X_3 - 5.06161X_1X_4 - 1331.43X_2X_3 - 522.143X_2X_4 - 577.786X_3X_4 + 27.6008X_1X_2X_3 + 13.971X_1X_2X_4 + 14.9795X_1X_3X_4 + 1585.71X_2X_3X_4 - 40.5672X_1X_2X_3X_4 \quad (2)$$

The data collected is used for analysis of Surface Roughness and the values of regression coefficients considering interactions are evaluated. The sample mathematical equations are given for TiCN PVD coating of 2.5 and 4 micron thickness on End Milling cutter as equation 1 and 2, also the R^2 and R^2 (Adj) values for each set of experiment for every coating thickness for surface roughness are given in table 6

Table 6: R^2 Values for Surface Roughness for 2.5 and 4 micron PVD coating thickness

Sr. No.	Coating Material	Coating Thickness (µm)	R^2 (%)	R^2 (Adjusted) (%)
1	TiCN	2.5	98.06	90.77
2	HELICA	2.5	97.16	86.49
3	AlCrN	2.5	97.62	88.69
4	TiAlN	2.5	97.86	89.83
5	TiN	2.5	98.79	94.24
6	TiCN	4	96.96	85.57
7	HELICA	4	98.17	91.29
8	AlCrN	4	99.29	96.64
9	TiAlN	4	99.64	98.28
10	TiN	4	99.51	97.68

4. OPTIMIZATION OF SURFACE ROUGHNESS USING RESPONSE SURFACE METHODOLOGY

Response Surface Methodology is collection of mathematical and statistical techniques that are useful for modeling, analysis and optimization of the problems, in which responses of interest are influenced by several input parameters and the objective is to optimize the responses. RSM gives the relationship between one or more measured responses and input parameters.

Table 7. Local Solution obtained in RSM

Local Solution		
Input parameter	2.5 micron	4 micron
V (m/min)	56.52	56.52
F (mm/rev)	0.33	0.33
D (mm)	0.25	0.2540
% C(by wt)	0.267	0.4

Table 8. Optimum Surface Roughness & Desirability

Coating Material	Predicted Responses			
	2.5 micron		4 micron	
	Ra (µm)	Desirability	Ra (µm)	Desirability
TiCN	1.70	0.95	1.55	1.00
HELICA	1.97	0.84	1.85	0.78
AlCrN	1.83	0.86	1.39	1.00
TiAlN	1.84	0.89	1.40	0.99
TiN	1.81	0.85	1.41	0.98
Combined Desirability	0.88		0.94	

The d optimality test was performed using MINITAB 16 for PVD coating thickness of 2.5 and 4 micron. The local optimum solution for each coating thickness is given in table 7 and 8. The optimization plots and contour plots for each coating material are shown in figure 1 to 4.

The optimization plots for 2.5 micron PVD coating thickness is as shown in figure 1 and that for 4 micron is shown in figure 2 and contour plots for TiCN for 2.5 and 4 micron are shown in figure 3 and 4 also response surfaces are drawn for TiCN and shown in figure 5 and 6.

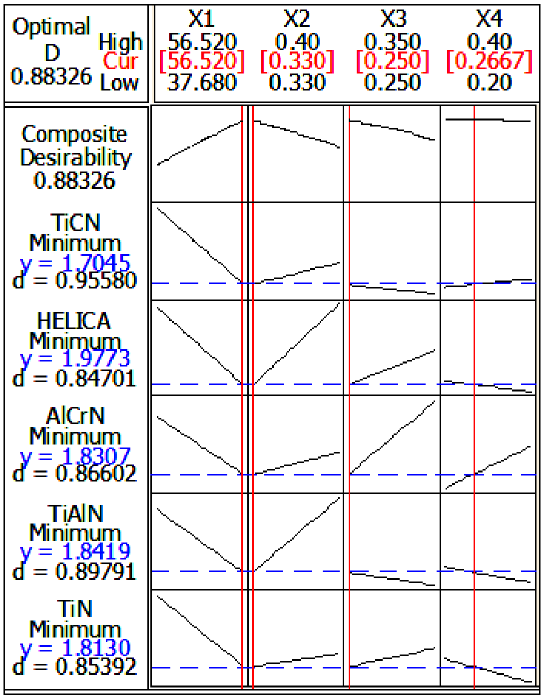

Fig. 1. The optimization plot for t =2.5 micron

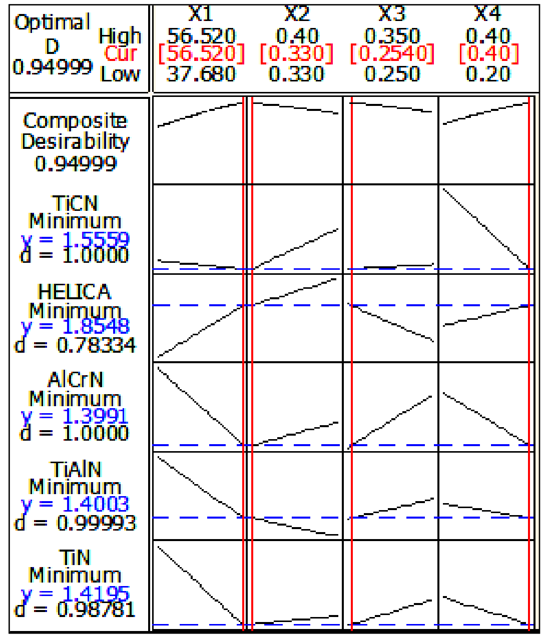

Fig. 2 .The optimization plot for t = 4 micron

The contour plots of TiCN for 2.5 and 4 micron PVD coating are given below in figure 3 and 4.

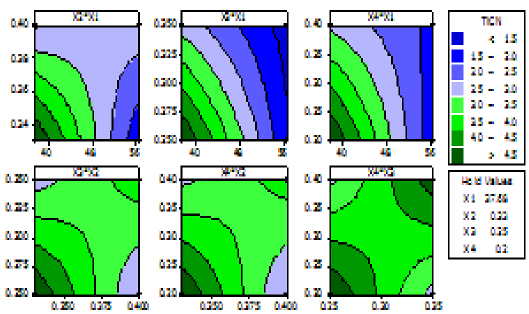

Fig. 3 Contour Plots for t = 2.5 micron

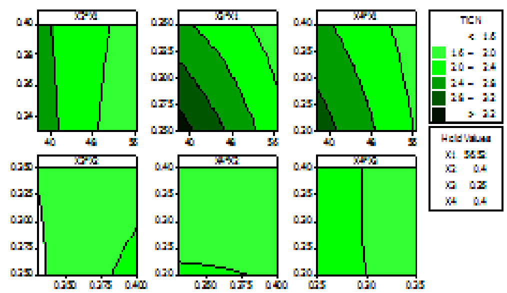

Fig. 4 Contour Plots for t = 4 micron

5. CONCLUSION

In this work PVD coated End Milling Cutters of different coating thickness are investigated to optimize process parameters for the improvement of surface roughness. Based on the experimental observation following conclusion are drawn:

1. The PVD coating materials TiCN, HELICA, AlCrN, TiAlN and TiN with coating thickness of 2.5 micron gives minimum values of Surface Roughness as 1.70, 1.97, 1.83, 1.84 and 1.81µm respectively. From the analysis that for 2.5 micron PVD coating thickness the least surface roughness (1.70 µm) for TiCN PVD coating was obtained.

2. The PVD coating materials TiCN, HELICA, AlCrN, TiAlN and TiN with coating thickness of 4 micron gives minimum values of surface roughness as 1.55, 1.85, 1.39, 1.40 and 1.41 µm respectively. From the analysis that for 4 micron PVD coating thickness the least surface roughness (1.39) for AlCrN PVD coating was obtained.

3. The optimum combination of parameters gives surface roughness of 1.39 µm for PVD coating of AlCrN with 4 micron thickness.

4. The composite desirability for 2.5 and 4 micron coating thickness of various coating materials is 0.88 and 0.94 respectively.

5. The local solution for 2.5 micron PVD coating thickness is V=56.52 m/min, F= 0.33 mm/rev, D=0.25 mm and %C=0.2 by wt for smaller values of surface roughness.

6. The local solution for 4 micron PVD coating thickness is V=56.52 m/min, F= 0.33 mm/rev, D=0.254 mm and %C=0.4 by wt for smaller values of surface roughness.

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