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Effect of cutting parameters on surface roughness and Tool wear for turning of AISI H13 die steel

Jagjeet Singh[1],Inderjeet Singh[2], Ravinder Singh[3], Amandeep Singh Bains [4]

[1]*Mechanical Engineering,CEC Landran Mohali, Punjab*
[2]*Mechanical Engineering,CEC Landran Mohali, Punjab*
[3]*Mechanical Engineering,CEC Landran Mohali, Punjab*
[4]*Mechanical Engineering,CEC Landran Mohali, Punjab*

Abstract —*Manufacturers of modern industries required higher production rate with required surface finish value and low tool wear so that the cost of manufacturing can be minimized combination with the reduced manufacturing time. Current research work utilizes response surface methodology (RSM) for modeling to predict surface roughness and tool wear for variety of cutting conditions in finish hard turning. In this paper hard turning of AISI H13 steel with coated carbide tools have been done at different cutting conditions. From the experimental data obtained it concluded that the coated carbide tools more economical and Surface roughness increases with increase in cutting speed and it decreases with decrease in feed rate.Tool wear increase with increase in feed rate as well as depth of cut.*

Keywords: *RSM, Tool wear, feed rate , depth of cut*

I. INTRODUCTION

Hard turning is a turning operation done on various alloy steel having hardness value 45 to 65 HRc to obtain surface roughness values that are close to those obtained in grinding (Ra ~ 0.1 _m). There are different materials which is hard turned like alloy steels, tool steels, case-hardened steels, super alloys, nitrided irons and hard-chrome-coated steels, and heat-treated powder metallurgical parts.(Aslantas 2011). Hard turning is of great interest of today's manufacturing industries because it produces desirable surface quality in lesser time as compare to grinding process, estimates of reduced machining time are as high as 60% for conventional hard turning (Huddle 2001).

Ji Xiong *et. al.*, (2012) experimentally studied tool wear and tool life of AISI H13 tool steel during hard turning with WC–5TiC–10Co ultrafine cemented carbides. In this study it was established that WC–5TiC–10Co ultrafine cemented carbides possess higher hardness and transverse rupture strength, and showed better cutting performance than conventional insert with the same cutting condition [1]. Uhlmann *et. al.*, (2010) had investigated the tool wear of CVD diamond coated cemented carbide tools in the machining of aluminium silicon alloys and found that the softer, hypo-eutectic G-AlSi9 Cu4Mg alloy has a high tendency to adhere to the rake face of the tool, causing built-up edge to be formed. The harder and more brittle hyper-eutectic alloy G-AlSi17 Cu4Mg is highly abrasive and so surface fatigue and abrasive wear led to fretting of the coating, spontaneous coating delamination as well as displacement of the cutting edge[2] . Noordin *et. al.*, (2007) experimentally performed hard turning under dry cutting conditions with constant depth of cut in order to investigate the usability of coated TiCN based cermet (KT 315) and coated carbide (KC 9110) cutting tools to turn tempered martensitic stainless tool steel. They concluded that that dry turning of hardened, stainless tool steel could be performed using coated TiCN based cermet and coated carbide cutting tools[3] . Prasad *et. al.*, (2011) experimentally performed hard turning with high speed steel tool and carbide insert tools to analyze the surface texture. They concluded that the carbide cutting tools provide better performance than high speed cutting tools. Quiza *et.al.*, (2008) had investigated the tool wear in hard machining D2 AISI steel using neural networks. In this study they concluded that neural network model has shown better capability to make accurate predictions of tool wear under the conditions studied [4] .

II. METHODOLOGY

The material used for the experiments was grade AISI H13 is one of the hot work, chromium type tool steels. It maintains high hardness and strength at elevated temperatures. Good resistance to thermal fatigue, erosion and wear. H13 finds applications for hot die work, die casting and extrusion dies, wear resisting tools, pressure die casting tools, pressing tools for light and heavy metal. The chemical compositions of the workpiece material are given in Table 1.

Table 1 Chemical Composition of AISI H13 steel [2]

Alloying element	C	S	P	Si	Ni	Cr	Mo	V
Percentage by weight	0.370	0.014	0.019	0.800	–	5.100	1.450	0.910

The Carbide inserts of Kyocera company, TNGA 160408S01525 (ISO Designation) PVD coated having nose radius 0.8 mm were employed. The machine tool employed for turning was BATLIBOI make CNC turning centre, model SPRINT 16TC with Fanuc 0i T Mate Model, Fanuc Motors & Drives and φ165 x 3 jaw Hydraulically operated. The Mitutoyo's Microscope TM-500 series was used to measure the width of flank wear. It is designed with measurement of work piece contours and inspection of surface features. The magnification and the least count of the instrument used is 30 X and 0.001 mm respectively. The stylus type surface roughness tester [5] having stroke length, 12.5 mm and evaluation length of 4 mm was used to evaluate the surface texture.

III DESIGN OF EXPERIMENTS

The response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [3] . The machining experiments and analysis were conducted based on response surface methodology (RSM) and the BOX-Behnken Design of experiments. Response-surface methodology comprises a body of methods for exploring for optimum operating conditions through experimental methods. The BOX-Behnken Design is one of many that can minimize the number of results required for three factor experimental design. The levels of the cutting parameters have been selected by taking into account, according to the recommendations of Kyocera and literature survey[7].

Table 2 Cutting parameters and there levels for coated carbide

Cutting parameters	Low level (-1)	Middle level (0)	High level (+1)
Cutting velocity V_c (m/min)	65.00	82.50	100.00
Feed rate f (mm/rev)	0.05	0.10	0.15
Depth of cut a_p (mm)	0.20	0.35	0.50

Table 3 Experimental design and cutting conditions for coated carbide

Run	Vc m/min	f mm/rev	D.O.C mm	Surface roughness(Ra) µm	Tool wear (V_B) Mm
1	82.50	0.10	0.35	1.7	0.135
2	100.00	0.15	0.35	0.91	0.186
3	82.50	0.05	0.20	0.89	0.153
4	82.50	0.10	0.35	1.55	0.176
5	65.00	0.10	0.20	1.74	0.133
6	100.00	0.10	0.20	1.15	0.237
7	100.00	0.10	0.50	1.65	0.138
8	65.00	0.15	0.35	1.53	0.126
9	100.00	0.05	0.35	1.58	0.133
10	82.50	0.10	0.35	1.98	0.145
11	82.50	0.10	0.35	0.87	0.184
12	82.50	0.05	0.50	1.27	0.267
13	82.50	0.15	0.50	1.98	0.145

14	65.00	0.05	0.35	1.28	0.287
15	65.00	0.10	0.50	1.63	0.123
16	82.50	0.15	0.20	0.89	0.147
17	82.50	0.10	0.35	1.18	0.272

The total 17 numbers of experiments were conducted under different cutting conditions and levels. The Table 3 shows the list of tests conducted with various combinations of cutting parameters and levels. Finally, regression models have been obtained and analyzed using analysis of variance (ANOVA).

IV RESULTS AND DISCUSSION

In the present study shows the suggested models for response, minimum and maximum ranges of response and cutting parameter. Adequacy of the model was checked by conducting three different tests viz. sequential model sum of squares, lack of fit and model summery statistics and results was tabulated as below:

Table 4 Design Summery for coated carbide

Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y1	Tool Wear	mm	17	0.10	1.07	None	RQuadratic
Y2	Surface roughness	µm	17	0.40	3.06	None	No model chosen
Factor	Name	Units	Type	Low actual	High actual	Low coded	High coded
A	Cutting speed	m/min	Numeric	65.00	100.00	-1.000	1.000
B	Feed	mm/rev	Numeric	0.050	0.15	-1.000	1.000
C	Depth of cut	mm	Numeric	0.20	0.50	-1.000	1.000

Table 5 Sequential model sum of squares for surface roughness (R_a)

Source	Sum of squares	DF	Mean Square	F Value	Prob > F	
Mean	14.04	1	14.04			Suggested
Linear	1.44	3	0.48	1.26	0.3295	
2FI	1.78	3	0.59	1.86	0.2009	
Quardric	2.06	3	0.69	4.23	0.0531	Suggested
Cubic	0.05	3	0.35	15.39	0.0116	Aliased
Residual	0.091	4	0.023			
Total	20.46	17	1.20			

Table 6 Lack of fit tests for surface roughness (R_a)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	4.88	9	0.54	23.95	0.0039	
2FI	3.10	6	0.52	22.84	0.0046	
Quardratic	1.05	3	0.35	15.39	0.0116	Suggested
Cubic	0.000	0				Aliased
Pure Error	0.091	4	0.023			

Table 7 Model Summary Statistics for Surface roughness (R_a)

Source	Std. Dev.	R-Square	Adjusted R-Square	Predicted R-Squared	PRESS	
Linear	0.62	0.2250	0.0461	-0.5065	9.67	
2FI	0.57	0.5022	0.2034	-1.0763	13.32	
Quardratic	0.40	0.8229	0.5952	-0.6301	16.88	Suggested
Cubic	0.15	0.9859	0.9435		+	Aliased

4.1 Analysis of Variance (ANOVA) for surface roughness with coated carbide

ANNOVA table 8 shows that the model is significant and model F-Value of 11.31 implies the model is significant. T'Pred R-Squared' of 0.2024 is in reasonable agreement with the 'Adj R-Squared' of 0.6590.

Table 8 ANNOVA for reduced quadratic model for surface roughness (R_a)
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Source	Sum of Squares	DF	Mean Squares	F Value	Prob > F	
Model	4.64	3	1.55	11.31	0.0006	Significant
A	1.06	1	1.06	7.74	0.0156	
B^2	1.90	1	1.90	13.92	0.0025	
AB	1.68	1	1.68	12.26	0.0039	
Residual	1.78	13	0.14			
Lack of Fit	1.69	9	0.19	8.28	0.0285	Significant
Pure Error	0.091	4	0.023			
Cor Total	6.42	16				
Std. Dev.		0.37		R-squared		0.7229

Mean	0.91	Adj R-Squared	0.6590
C.V.	40.69	Pred R-Squared	0.2024
PRESS	5.12	Adeq Precision	11.403

4.1.1 Response surface model for surface roughness (R_a)

The empirical linear model developed for R_a during the hard turning of AISI H13 steel with coated carbide tool under dry cutting conditions. Surface roughness R_a = +0.59 -0.36*cutting speed +0.67*feed^2 +0.65*cutting speed*feed. Thediagnostic checking of the model has been carried out using data from table 5.19 and the results are presented in figure 4 and 5. shows the standardized residuals with respect to the predicted value. Figure 6 shows the effect of cutting speed, feed, and depth of cut on $R_{a.}$ the actual factors are A cutting speed 82.50 m/min, B feed 0.10 mm/rev and C depth of cut 0.35mm.The graph indicate that the with increase in cutting speed surfae roughness increases and it decreases with increase in feed.

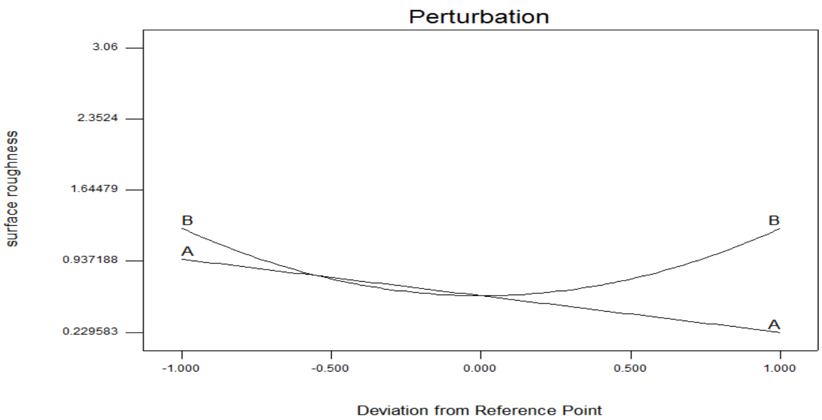

Figure 6 Effect of cutting parameters on surface roughness R_a

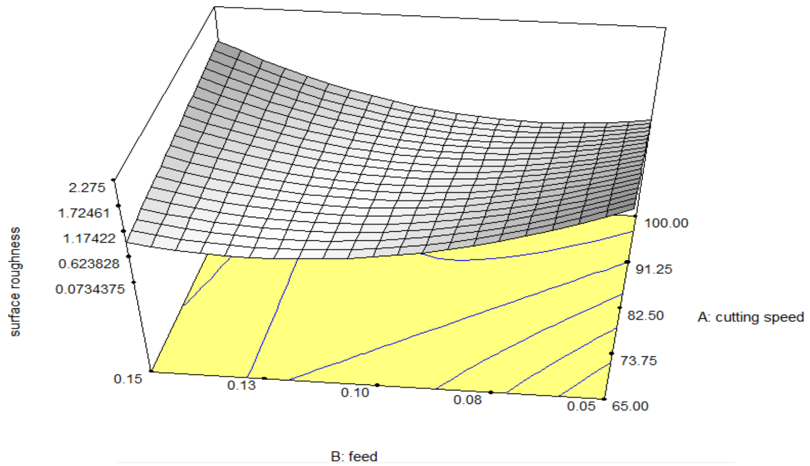

Figure 7 3D plot for surface roughness

Figure 7 Shows the interaction between cutting speed, feed, and surface roughness. It shows that the at low and high cutting speed and feed combinations surface roughness increases. Surface roughness value is least at low feed rate higher cutting speed combination and surface roughness value is highest at higher feed rate highter cutting speed combinations.

4.2 Analysis of Variance (ANOVA) for tool wear with coated carbide

The same procedure was adopted to decide about the adequacy of the model and three different tests viz. sequential model sum of squares, lack of fit tests and model summary statistics were conducted and the quadratic model was suggested by response surface methodology.

Table 9 ANNOVA for Response Surface Reduced Quadratic Model for Tool Wear

Source	Sum of squares	DF	Mean Squares	F value	Prob > F	
Model	1.519E-003	5	3.307E-004	11.40	0.0005	Significant
A	*3.001E-003*	1	*3.001E-004*	*11.26*	0.0064	

B	*2.311E-004*	1	*2.311E-004*	*8.67*	0.0133	
C	*5.780E-004*	1	*5.780E-004*	*21.69*	0.0007	
B^2	*1.843E-004*	1	*1.843E-004*	*6.92*	0.0234	
AB	*2.250E-004*	1	*2.250E-004*	*8.44*	*0.0143*	
Residual	2.932E-004	11	2.665E-005			
Lack of Fit	2.704E-004	7	3.863E-005	6.78	0.0417	Significant
Pure Error	*2.280E-005*	4	5.700E-006			
Cor Total	1.812E-003	16				

42.1 Response Surface model for tool wear

The empirical linear model developed for tool wear during the hardturning of AISI H13 steel is given below:
Final equation in terms of actual factor

Tool wear = +0.020411 +5.07143E-004* cutting speed +1.34242* feed +0.056667* depth of cut -2.63889* feed2 - 8.57143E-003* cutting speed * feed

The diagnostics checking of model has been carried out using the data from the table 4.19 and the results are shown in the figures 8(Normal Plot of Residuals) and 9(Plot of Residual v/s Predicted Response). The residual v/s predicted indicates that the distribution of residuals do not show any obvious pattern and are distributed in both positive and negative direction. This indicates that the model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

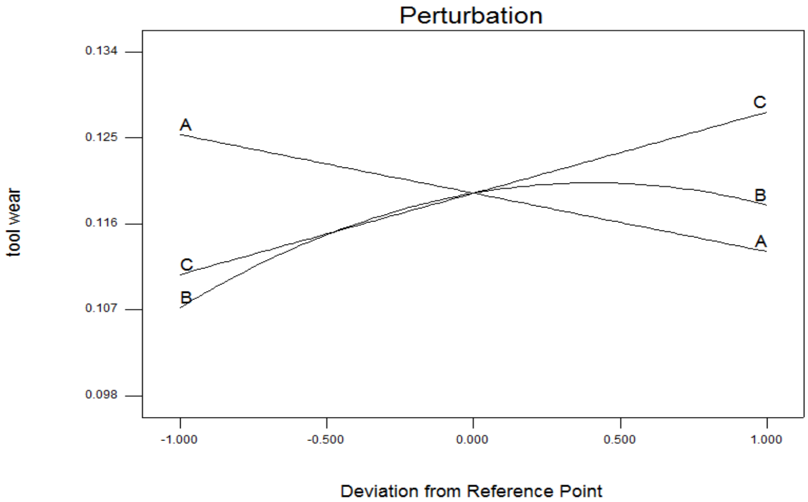

Figure 10 Effect of cutting parameters on tool wear

The effect of cutting parameters is shown in figure 10, in this figure the effect of cutting speed is linear and tool wear reduces with increase in speed, tool wear increases with increase in feed and depth of cut.

The same procedure was adopted to decide about the adequacy of the model and three different tests viz. sequential model sum of squares, lack of fit tests and model summary statistics were conducted and the quadratic model was suggested by response surface methodology.

4.2.2 Analysis of Variance (ANNOVA) for Tool Wear

The model F value of 61.42 implies the model is significant as shown in table 11. The value of 'Prob > F' less than 0.05 indicate that model is significant. In this case A, B, A^2, C^2 are the significant terms and C is the in significant term. After removing the insignificant terms the table formed is table 10 .

Table 10 ANNOVA for Response Surface Reduced Quadratic Model for Tool Wear

Source	Sum of squares	DF	Mean Squares	F value	Prob > F	
Model	0.047	4	0.012	61.42	< 0.0001	Significant

A	0.036	1	0.036	*188.38*	< 0.0001	
B	1.770E-003	1	*1.770E-003*	*9.29*	0.0101	
A^2	*7.669E-003*	1	*7.669E-003*	*40.23*	< 0.0001	
C_2	*1.131E-003*	1	*1.131E-003*	*5.93*	0.0314	
Residual	2.288E-003	12	1.906E-004			
Lack of Fit	*1.034E-003*	8	*1.293E-004*	0.41	0.8666	Not significant
Pure Error	*1.253E-003*	4	*3.133E-004*			
Cor Total	0.049	16				

V.CONCLUSION

This research work presents the comparison of cutting tool performance in terms of tool wear and surface roughness of coated carbide tools under dry cutting conditions and the following conclusions are drawn.

I. Surface roughness increases with increase in cutting speed and it decreases with decrease in feed rate.
II. Tool wear increase with increase in feed rate as well as depth of cut.
III. Less tool wear in case of coated carbide tools they are more suitable and economical for turning of AISI H13 hot die steel.

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