Experimental Investigation of surface roughness in dry turning of AISI 4340 alloy steel using PVD- and CVD- coated carbide inserts

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Abstract - The performance of coated inserts was described using Response Surface Methodology (RSM) when turning AISI 4340 alloy steel using single layer PVD and triple layer CVD coated inserts. Cutting tests were performed under dry cutting conditions so as to reduce the effects of cooling agents on the environment. Surface roughness (Ra) was the main response variable investigated. The experimental plan was based on the face centered, central composite design (CCD). The experimental results indicated that the proposed mathematical model suggested could adequately describe the performance indicators. Feed is the most significant factor affecting the surface roughness one followed by cutting speed. RAMP function plots and 3-D graphs shows the comparative effects of both the coatings of inserts on the work-piece surface roughness

Keywords: AISI 4340 alloy steel, Response Surface Methodology, ANOVA, PVD and CVD

I. INTRODUCTION

High productivity is the most important requirement in the machining process. But high productivity at the cost of poor surface finish is not acceptable. Surface roughness is considered as an index of product quality which makes it as the most desired outcome along with productivity. It measures the finer irregularities of the surface texture [1]. A good quality turning surface can lead to improvement in strength properties and functional attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing and holding a lubricant [2]. Various process parameters viz. cutting speed, feed rate, depth of cut, cutting environment, cutting insert, tool geometry, work-piece material etc. are responsible for the ability to obtain the desired surface roughness. Previous studies reflects the effects of cutting speed, feed rate, depth of cut, rake angle on the surface roughness. This study emphasize on the use of coated inserts so as to reduce the use of lubricant and reduce environment pollution.

Now-a-days 80% of all machining operations are performed with coated carbide cutting tools [3]. Hard turning had replaced application range of grinding in the areas of manufacturing shafts, gears, axles and other mechanical components made of materials having hardness range more than 45 HRC. This is due to the fact that hard turning reduces the cost per product in obtaining the surface finish close to grinding operation with higher productivity, less set up time, less costly equipment and an add on ability to machine complex contours. The specific cutting energy for the hard turning is found to be smaller than the specific grinding energy [3]. Trends toward machining difficult to cut materials lead to the development of high performance thin layer coatings. Mostly carbide tools are processed by physical vapour deposition (PVD) and chemical vapour deposition (CVD) so as to from a coating of material with properties like higher wear resistance and thermal shocks. Titanium based hard thin films are mostly used due to higher wear resistance, thermal shocks and corrosion property and also impart lubricity at the chip tool interface to reduce friction [3]. Luca Settineri [15] studied the properties and performances of innovative coated tools for turning Inconel. The coatings of TiN + AlTiN, TiN + AlTiN + MoS_2, and CrN + CrN:C + C were applied by PVD techniques on WC-Co inserts developing nanostructured layers. Coatings surface qualification included SEM observation with EDS analysis, ball erosion test, nano indentation, and scratch test.

Researchers always need to model and quantify the relationship between the roughness and its effecting parameters. Literature reveals that statistical design of experiments, in place of traditional one factor at a time approach, is the widely adopted technique for the process of planning the experiments so that appropriate data can be analysed by statistical methods. Makadia and Nanavati [1] used Design of Experiments to study the effect of the main turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on the surface roughness of AISI 410 steel. Surface contours were constructed using RSM for determining the optimum conditions for required surface roughness. Neseli, Yaldis, and Turkes [2] had investigated the influence of tool geometry on the surface finish obtained in turning of AISI 1040 steel. RSM was used and prediction model was developed related to average surface roughness using experimental data. Ashok Kumar and B C Routara [5] used Response Surface Methodology and Genetic Algorithm to optimize the cutting conditions for surface roughness parameters in CNC turning of EN-8 steel. Genetic Algorithm simulates biological evolution process- Darwin's theory of survival of the fittest. Mahendra Korat and Neeraj Aggarwal [6] studied experimentally to optimize the effects of various cutting parameters on surface finish of EN-24 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. M. Kaladhar [7] uses Taguchi's Design of Experiments approach to analyse the effect of process parameters during turning. Muammer and Hasan [8] investigated the effects of uncoated, PVD and CVD coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural network. Also J. Paulo Davim [9] investigated the effects of basic cutting parameters on surface roughness by ANN model. Ersan Aslan [10] studied the effect of cutting parameters in turning of AISI 4140 steel using Al_2O_3 + TiCN mixed ceramic tool and the design optimization was done with the help of taguchi technique. Kamal Hassan and Anish Kumar [11] also used taguchi technique to find the optimal set of process parameters while turning of medium brass alloy . Lalwani and Mehta [12] used response surface to investigate the influence of cutting parameters on surface roughness in finish hard turning of MDN250 steel. Ilhan Asilturk [13] studied the influence of cutting speed, feed rate and depth of cut on the surface roughness of dry turned AISI 304 Austenitic Stainless steel workpiece and a model for surface roughness as a function of cutting parameters was obtained using RSM and finally the adequacy of the developed mathematical model was proved by ANOVA. In present study Response Surface Methodology is used to design the experimental plan and then for further analysis of the responses.

II. EXPERIMENTAL CONDITIONS AND PROCEDURE.

Experiments were carried out to study the effects of coated tools on turned AISI 4340 alloy steel with 45-55 HRC hardness, in dry cutting conditions with PVD and CVD coated inserts. In this investigation the basic turning parameters viz. Cutting Speed (m/min.), feed rate (rev/min) and depth of cut (mm) were selected to perform cutting operation and the length of cut was taken as 30 mm. Total no. of 40 work pieces were cut and machined for this experiential investigation.

A. Test Specimen

The work material selected for the study was AISI 4340 medium alloy steel with high tensile strength, shock resistance, good ductility, and resistance to wear. The AISI 4340 is a difficult to machine material because of its high hardness, low specific heat and tendency to get strain hardened [8]. It is known for its toughness and capability of developing high strength in the heat treated condition while retaining good fatigue strength [8]. The AISI 4340 is high tensile strength general engineering steel ideal for automotive and aircraft components. Axles and axle components, extrusion liners, magneto drive coupling, shaft and wheels, pinion and pinion shafts, are the application range [8]. AISI 4340 alloy steel is mainly used in power transmission gears and shafts, aircraft landing gear, and other structural parts. The work pieces were hardened tempered to obtain the hardness range of 45-55 HRC. The chemical composition of the material contains 0.402 C, 0.238 Si, 0.597 Mn, 1.41 Ni, 0.0208 S, 1.09 Cr, 0.228 Mo, 0.0187 P.

B. Machine Tool.

Turning Experiments were performed on CNC turning Centre CL2050 BATLIBOI, Surat installed at Central Institute of Hand Tools, Jalandhar equipped with variable spindle speed of 30 to 4000 r.p.m and 5.5 kW (contiuous) spindle drive motor power with maximum diameter of 250mm and length 350mm.

C. Cutting Inserts

In tests, single layer (TiAlN) PVD Coated insert has been employed for experimentation. In this insert top layer is TiN which has a certain characteristic such as tendency to reduce built up edge, a higher coefficient of friction and thermal conductivity. These characteristics results in less thermal cracks and improves surface finish[7] The PVD process has a proven performance of over CVD process due to its low coating temperature deposition[7].

D. Cutting Conditions.

The cutting conditions for turning under different parametric conditions is shown in table 1

Table 1: Cutting Conditions for Turning

S.No.	Cutting conditions	Description
1	Work-piece	AISI-4340
2	Hardness	45-55 HRC
3	Cutting Speed	60, 70, 80 m/min
4	Feed	0.18, 0.20, 0.22 mm/rev.
5	Depth of Cut	0.3, 0.4, 0.5 mm
6	Cutting Environment	Dry.
7	Cutting Inserts	Triple Layer CVD (TiCN/Al2O3/TiN) and Single Layer PVD (TiAlN) inserts
8	Responses	Surface Roughness.

E. Surface Roughness Measurement.

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. In this work the surface roughness was measured by Mitutoyo Surftest SJ-201P. The surftest is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in µm. The work piece is attached to the detector unit of the SJ-201P which traces the minute irregularities of the work piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the SJ-201P.

III. EXPERIMENTATION

Turning is a widely used material removal process. The use of CNC turning machine has a proven record of better surface quality, precise accuracy, less machining times and high production rate in comparison to the conventional lathe machines. But the major problem being faced by the workers as well as the researchers while performing turning operations on such machines which require high set up cost, is to operate them with their best parameter selection so as to obtain the desired outputs more efficiently. In this paper a range of basic parameters was selected after performing pilot experiments by using one factor at a time approach and then using that range 20 set of experiments were designed with the help of Design Expert software. These 20 set of experiments were then performed with all the cutting conditions viz. CVD insert in wet condition, PVD insert in wet condition, CVD insert in dry condition and lastly PVD insert in dry condition. The output parameter was checked for all the condition and tabulated in table 2

Table 2: Experimental Observations.

Sr. No	Cutting Speed, V (m/min)	Feed, F (rev./min.)	Depth of Cut, D (mm)	Surface Roughness, Ra. (µm) (dry PVD)	Surface Roughness, Ra. (µm) (dry CVD)
1	70	0.2	0.4	1.78	2.31
2	70	0.23	0.4	2.56	3.14
3	70	0.2	0.4	1.72	2.29
4	60	0.18	0.3	1.43	1.52
5	80	0.18	0.5	1.58	1.69
6	70	0.2	0.4	1.68	2.28
7	70	0.2	0.6	1.69	2.39
8	60	0.22	0.3	2.59	2.61
9	70	0.2	0.4	1.74	2.29
10	60	0.22	0.5	2.63	2.59
11	53	0.2	0.4	1.82	1.69
12	60	0.18	0.5	1.39	1.65
13	80	0.22	0.3	1.62	2.59
14	80	0.22	0.5	1.61	2.59
15	80	0.18	0.3	1.59	1.53
16	70	0.2	0.4	1.71	2.31
17	70	0.2	0.2	1.72	2.24
18	70	0.2	0.4	1.82	2.29
19	87	0.2	0.4	1.52	1.79
20	70	0.17	0.4	1.59	1.51

IV.RESULTS AND DISCUSSION

The results from the machining trials performed as per the experimental plan were input into the Design Expert software for further analysis. Without performing any transformation on the response, examination of the fit summary reveals that the quadratic model is statistically significant and further test for significance of the regression model, and lack of fit was performed by using ANOVA analysis.

A. ANOVA Analysis

The ANOVA i.e. Analysis of Variance table is commonly used to summarize the tests performed. ANOVA table shows the significance of model. If the "Prob.> F" is less than 0.05, this indicates the model is significant which is desirable as it indicates the terms in the model have a significant effect on the responses. The lack of fit test in the ANOVA table shows that the model is ready to fit or not. Not significant lack of fit is desirable as we want the model to fit. The terms which are not significant are removed to improve the model. Table 3 shows the ANOVA table for Response Surface Reduced Quadratic Model for Surface Roughness measure of CNC turned AISI 4340 Alloy Steel using single layer PVD coated insert under dry cutting environment.

Table 3: ANOVA for Response Surface Reduced Quadratic Model (Response: Ra in dry PVD)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	2.45	4	0.61	120.86	< 0.0001	Significant
A-Cutting Speed	0.34	1	0.34	66.37	< 0.0001	
B-Feed	1.23	1	1.23	241.56	< 0.0001	
AB	0.68	1	0.68	134.89	< 0.0001	
B^2	0.21	1	0.21	40.62	< 0.0001	
Residual	0.076	15	5.07×10^{-3}			
Lack of Fit	0.063	10	6.32×10^{-3}	2.45	0.1669	not significant
Pure Error	0.013	5	2.58×10^{-3}			
Cor Total	2.53	19				
Std. Dev.	0.071		R-Squared	0.9699		
Mean	1.79		Adj R-Squared	0.9619		
C.V. %	3.98		Pred R-Squared	0.9408		
PRESS	0.15		Adeq Precision	33.248		

The Probability > F for the model in Table 3 is less than 0.05 which indicates that the model is significant. This is desirable as it indicates that the terms in the model have a significant effect on the response. In this case A, B, AB, B^2 are significant model terms. Model fitting with the help of Design-Expert software suggested that a quadratic model provided the best fit, and the model was found to have insignificant Lack of fit. This was desirable as we want a model that fits. The ANOVA table for reduced quadratic model indicated that the model is significant at $p < 0.0001$, and its Lack of fit was not significant. The R^2 value was high and close to one, which was desirable. The 0.9699 value of R^2 means that 96% of the variability of result can be explained by the model. The predicted R^2 value was in agreement with the adjusted R^2 but the difference is also considerable. Few better results with more experimentation can also be obtained. Adequate precision measures signal-to-noise ratio, computed by dividing the difference between the maximum predicted response and the minimum predicted response by the average standard deviation of all predicted responses. Ratios greater than 4 are desirable. In this case the value is 33.248 which is above 4, indicating the presence of signals to use this model to navigate the design space. PRESS stands for "Prediction Error Sum of Squares" and it is a measure of how well the model for the experiment is likely to predict the responses in a new experiment. Small values of PRESS are desirable. In this case the value is 0.15

The following equation (equation 1) is the final empirical model in terms of actual factors.

Surface Roughness (Ra.)

$$Ra. = - 8.81233 + 0.27680 \times V - 1.15286 \times F - 1.46250 \times V \times F + 296.26732 \times F^2 \text{.........} \qquad (1)$$

The normal probability plots of residuals and the plots of the residuals vs. the predicted responses for the surface roughness are shown in Fig. 1& 2. A check on the plots in fig. 1 shows that all the residuals generally falls on the straight line implying that the errors are distributed normally and also Fig.2 revealed that they have no obvious pattern and unusual structure. This implies that the proposed model has no reason to suspect any violation of the errors being normally and independently distributed and finally the model proposed is adequate.

The 3D surface graphs for surface roughness shown in Fig. 3& 4 have curvilinear profile in accordance to the quadratic model fitted.

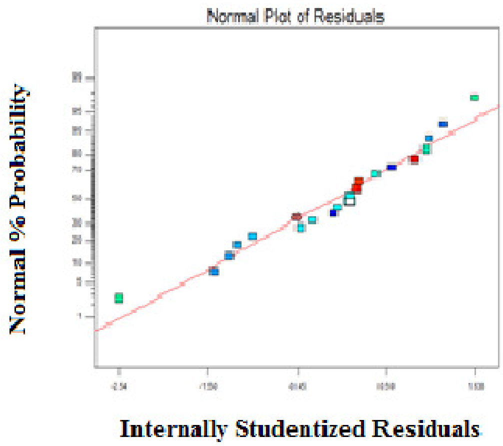

Fig.1: Normal Probability Plot of Residuals of cutting speed and feed on surface roughness parameters

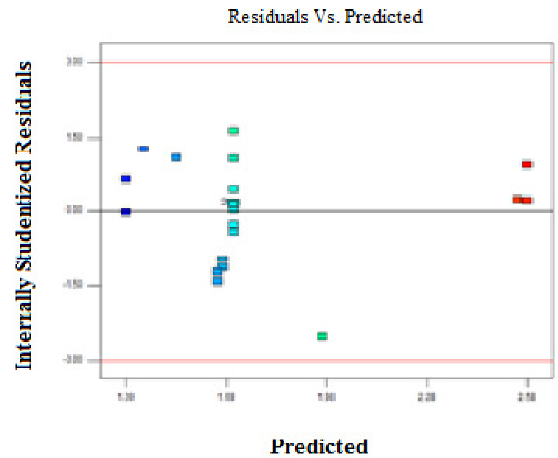

Fig.2: Plot of Residuals vs. Predicted Responses of cutting speed and feed on surface roughness parameters

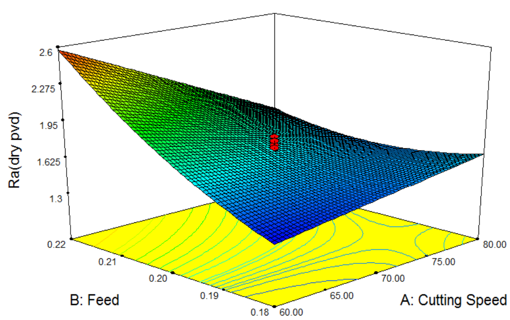

Fig. 3: Interaction effects of cutting speed and feed on surface roughness parameters

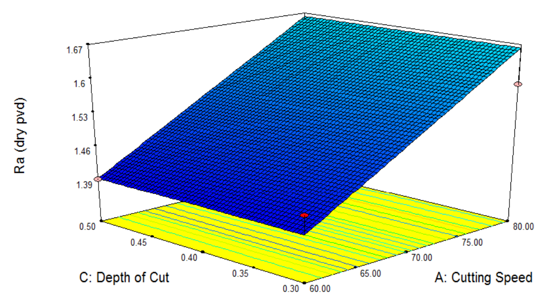

Fig.4: Interaction effects of cutting speed and depth of cut on surface roughness parameters

The above graphs revealed that the value of surface roughness increases with the increase in cutting speed which is an unusual effect as usually the value of cutting speed increases to some extent but after few runs it starts decreasing. In case of dry turning with PVD coated inserts the trend is somewhat different as the value of surface roughness is increasing. Also it is evident that the value of surface roughness increases with the increase in feed rate and this increase is very significant. Depth of cut has an insignificant effect on the value of surface roughness as the value remains almost constant. Considering the same plots for the response output in case of dry turning with CVD coated inserts shows a bit different result. Table 4 shows the ANOVA analysis for response surface quadratic model for response Ra in dry CVD.

Table 4: ANOVA for Response Surface Reduced Quadratic Model (Response Ra in dry CVD)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	3.95	5	0.79	1594.9	< 0.0001	Significant
A-Cutting Speed	2.88×10^{-3}	1	2.88×10^{-3}	5.81	0.0303	
B-Feed	3.32	1	3.32	6702.8	< 0.0001	
C-Depth of Cut	0.02	1	0.02	40.35	< 0.0001	
BC	0.012	1	0.012	24.27	0.0002	
A^2	0.59	1	0.59	1201.5	< 0.0001	
Residual	6.93×10^{-3}	14	4.95×10^{-4}			
Lack of Fit	6.18×10^{-3}	9	6.87×10^{-4}	4.58	0.0543	not significant
Pure Error	7.50×10^{-4}	5	1.50×10^{-4}			
Cor Total	3.95	19				
Std. Dev.	0.022		R-Squared	0.9982		
Mean	2.16		Adj R-Squared	0.9976		
C.V. %	1.03		Pred R-Squared	0.995		
PRESS	0.02		Adeq Precision	136.05		

The Probability> F for the model in Table 4 is less than 0.05 which indicates that the model is significant. This is desirable as it indicates that the terms in the model have a significant effect on the response. In this case A, B, C, BC, A^2 are significant model terms. Model fitting with the help of Design-Expert software suggested that a quadratic model provided the best fit, and the model was found to have insignificant Lack of fit. This was desirable as we want a model that fits. The ANOVA table for reduced quadratic model indicated that the model is significant at $p < 0.0001$, and its Lack of fit was not significant. The R^2 value was high and close to one, which was desirable. The 0.998 value of R^2 means that 99% of the variability of result can be explained by the model. The predicted R^2 value was in reasonable agreement with the adjusted R^2. Adequate precision measures signal-to-noise ratio, computed by dividing the difference between the maximum predicted response and the minimum predicted response by the average standard deviation of all predicted responses. Ratios greater than 4 are desirable. In this case the value is 136.05 which is well above 4, indicating adequate signals to use this model to navigate the design space. PRESS stands for “Prediction Error Sum of Squares” and it is a measure of how well the model for the experiment is likely to predict the responses in a new experiment. Small values of PRESS are desirable. In this case the value is 0.02

The following equation (equation 2) is the final empirical model in terms of actual factors.

Surface Roughness (Ra.)

$$Ra. = -14.29529 + 0.28329 \times V + 32.39448 \times F + 4.25742 \times D - 19.37500 \times F \times D - 2.01312 \times 10^{-3} \times V^2 \qquad (2)$$

The normal probability plots of residuals and the plots of the residuals vs. the predicted responses for the surface roughness are shown in fig. 5-6. A check on the plots in fig. 5 shows that all the residuals generally falls on the straight line implying that the errors are distributed normally and also fig.6 revealed that they have no obvious pattern and unusual structure. This implies that the proposed model has no reason to suspect any violation of the errors being normally and independently distributed and finally the model proposed is adequate.

The 3D surface graphs for surface roughness shown in fig. 7-8 have curvilinear profile in accordance to the quadratic model fitted.

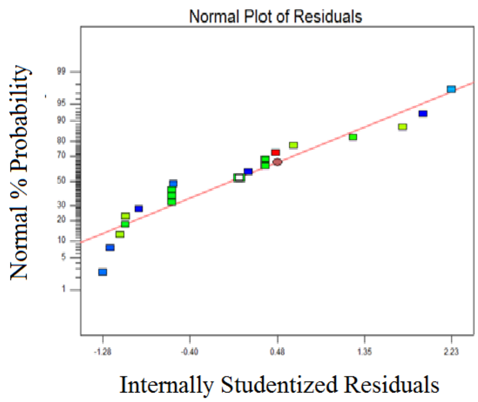

Fig.5: Normal Probability Plot of Residuals of cutting speed and feed on surface roughness parameters

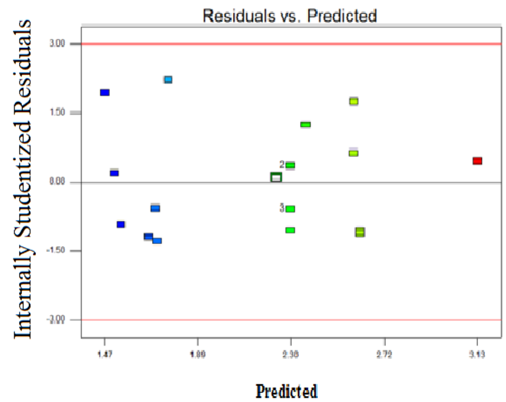

Fig.6: Plot of Residuals vs. Predicted Responses of cutting speed and feed on

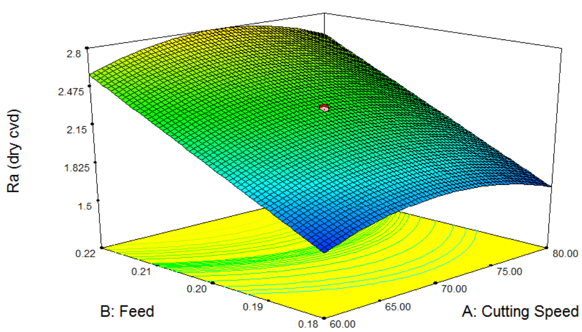

Fig.7: Interaction effects of cutting speed and feed on surface roughness parameters

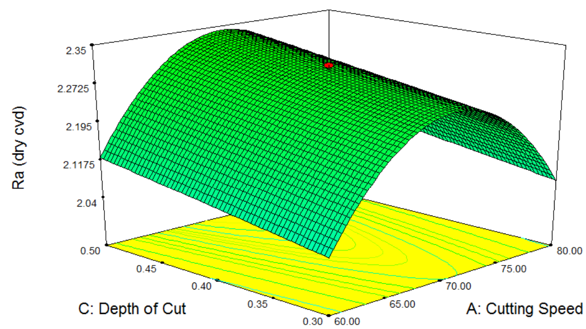

Fig.8: Interaction effects of cutting speed and depth of cut on surface roughness

The above plots revealed that the value of surface roughness shows a general trend of increasing to some extent and then decreases with the increase in cutting speed. It is also evident that the increasing feed rate significantly raises the graph of surface roughness. And the value of depth of cut has not much effect on surface roughness. The above results and plots for the values of surface roughness obtained shows that the 3-D graphs of variation with change in feed rate and depth of cut is almost similar in case of both types of inserts CVD as well as PVD but there is a difference in the graphs obtained during variation in cutting speed. PVD coatings shows better results in this case as the values of surface roughness

Desirability is an objective function that ranges from zero outside of the limits to one at the goal. The numerical optimization finds a point that maximizes the desirability function. Ramp function graphs of the material for mnimum Ra. are shown in Figure 9 and 10 for turning with PVD and CVD inserts respectively. It is revealed from the graphs that the minimum value of Surface roughness in case of turning with PVD coated inserts, 1.39 microns and the desirability value is 0.998. The best setting of the parameters is: cutting Speed (V) = 60 m/min., Feed(F) =0.18 mm/rev.and Depth of Cut (D) = 0.50 mm,In case of turning with CVD coated insert minimum value of surface roughness is 1.51 microns. and the desirability value is 0.996. The best setting of the parameters is: cutting Speed (V) = 60 m/min., Feed(F) =0.18 mm/rev.and Depth of Cut (D) = 0.30 mm.

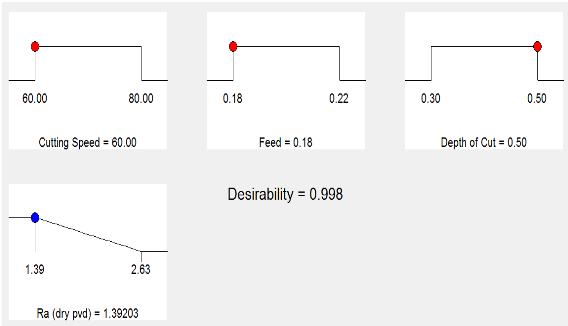

Fig. 9: Ramp Function graph for surface roughness (Ra.) in case of dry turning with PVD insert

Fig. 10: Ramp Function graph for surface roughness (Ra.) in case of dry turning with CVD insert

The above plots reveals that the PVD coatings show better results than CVD coatings as the value of surface roughness is less in that case. Moreover the desirability of such result is high in case of PVD insert. Also it is evident that the PVD inserts shows better surface finish at same cutting speed, feed rate and a higher value of depth of cut which is desirable as according to theories of machining it is clear that the manufacturing cost decreases with the operations performed at higher parametric conditions as the manufacturing cost is associated with machining time to some extent.

V.CONCLUSION

This paper experimentally investigates the effect of cutting speed, feed and depth of cut on the value of surface roughness while performing the turning operation in dry cutting condition with PVD and CVD coated inserts. ANOVA revealed that feed is the most influencing parameter with depth of cut to be the least one. The reduced quadratic models developed using RSM were reasonably accurate and can be used for prediction.

REFERENCES

[1] Ashvin J. Makadia, J.I. Nanavati, "Optimization of Machining Parameters for Turning Operations Based on Response Surface Methodology", *Measurement, vol. 46, p.p 1521-1529, 2013*

[2] Suleyman Neseli, SuleymanYaldiz, Erol Turkes, "Optimization of Tool Geometry Parameters for Turning Operation Based on the Response Surface Methodology", *Measurement, vol. 44, p.p 580-587,2011*

[3] Ashok K Sahoo, BidyadharSahoo,"Experimental Investigations on Machinability Aspects in Finish Hard Turning of AISI-4340 Steel using Uncoated and Multicoated Carbide Inserts", *Measurements vol.45, p.p 2153-2165, 2012*

[4] M.Y.Noordiin, V.C. Venkatesh, S. Sharif, A. Abdullah, "Application of Response Surface Methodology in Describing the Performance of Coated Carbide Tools when Turning AISI 1045 Steel", *Journal of Materials Processing Technology, vol. 145, p.p 46-58, 2004.*

[5] B.C. Routera, A.K. Sahoo, A.K. Paradia and PC. Padhi," Response Surface Methodology and Genetic Algorithm used to Optimize the Cutting condition for Surface Roughness Parameter in CNC Turning", *Procedia Engineering, vol. 38, p.p 1893-1904, 2012.*

[6] Mahendra Korat, Neeraj Agarwal," Optimization of Different Machining Parameters of En24 Alloy Steel in CNC Turning by use of Taguchi Method", *International Journal of Engineering Research and Applications, vol.2, issue 5, p.p 160-164, 2012.*

[7] M. Kaladhar, K. VenkataSubbaiah, Ch. Srinivasa Rao, "Performance Evaluation of Coated Materials and Process Parameters Optimization for Surface Quality during Turning of AISI 304 Austenitic Stainless Steel", *International Journal of Engineering Science and Technology vol.3, Issue 4, p.p 89-102, 2011.*

[8] S.R.Das, D. Dhupal, A. Kumar," Experimental Study and Modelling of Surface Roughness in Turning of Hardened AISI 4340 Steel Using Coated Carbide Inserted", *International Journal of Automotive Engineering vol.3,p.p 284-292, 2013*.

[9] Muammer Nalbant, Hasan Gokkaya, IhsanToktas, Gokhan Sur, "The Experimental Investigation of the Effects of Uncoated, PVD- and CVD- Coated Cemented Carbide Inserts and Cutting Parameters on Surface Roughness in CNC Turning and its Prediction using Artificial Neural Networks", *Robotics and Computer Integrated Manufacturing, vol. 25, p.p 211-223, 2009.*

[10] J. Paulo Davim, V.N. Gaitonde, S.R. Karnik, "Investigations into the Effect of Cutting Conditions on the Surface Roughness in Turning of Free Machining Steel by ANN Model", *Journal of Materials Processing Technology vol.205 p.p 16-23, 2008.*

[11] ErsanAslan, Necip Camuscu, Burak Birgoren, "Design Optimization of Cutting Parameters when Turning Hardened AISI 4140 Steel (63 HRC) with Al_2O_3+ TiCN Mixed Ceramic Tool, *Materials and Design vol. 28, p.p 1618-1622, 2007*.

[12] Kamal Hassan, Anish Kumar, M.P.Garg, "Experimental Investigation of Material Removal Rate in CNC turning using Taguchi Method", *International Journal of Engineering Research and Applications 2,(2012), Issue 2, 1581-1590*

[13] D.I. Lalwani, N.K.Mehta, P.K.Jain, Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel, Journal of Materials Processing technology vol. 206, p.p 167-179, 2008.

[14] Ilhan Asilturk, Suleyman Neseli, "Multi Response Optimization of CNC Turning Parameters via. Taguchi Method Based Response Surface Analysis", *Measurement vol. 45, p.p. 785-794, 2012.*

[15] Luca Settineri, Maria Giulia Faga, Beatriz Lerga," Properties and Performances of Innovative Coated Tools for Turning Inconel", *International Journal of Machine Tools & Manufacture, vol. 48, p.p. 815-823, 2008.*