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ESTIMATING THE EFFECT OF MACHINING PARAMETERS ON SURFACE ROUGHNESS DURING MACHINING OF HARDENED EN24 STEEL USING COATED CARBIDE INSERTS

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Abstract- In the present study, an attempt has been made to evaluate the performance of multilayer coated carbide inserts during dry turning of hardened EN24 steel (47 HRC). The effect of machining parameters (depth of cut, feed and cutting speed) on surface roughness parameters (Ra and Rz) were investigated by applying ANOVA. The experiments were planned based on Taguchi's L_{27} Orthogonal array design. Results showed that surface roughness parameters (Ra and Rz) are mainly influenced by feed and cutting speed, whereas depth of cut exhibits minimum influence on surface roughness (Rz) and neglegible influence in case of surface roughness (Ra). The experimental data were further anlyzed to predict the optimal range of surface roughness parameters (Ra and Rz). Finally, second order regression models were carried out to find out the relationship between the machining parameters and surface roughness parameters.

Keywords- EN24 steel, Surface roughness, Taguchi design, ANOVA.

I. INTRODUCTION

THE achivement of high quality, in terms of workpiece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced enviornmental impact are the main and effective challenges of modern metal cutting and machining industries [1,2,3]. Traditionally, hardened steels are machined by grinding process due to their high strength and wear resistance properties but grinding operations are time consuming and limited to the range of geometries to be produced. In recent years, machining the hardened steel in turning which uses a single point cutting tool has replaced grinding to some extent for such application. This leads to reduced the number of setup changes, product cost and ideal time without compromising on surface quality to maintain the competiveness [4,5]. The improve technological process, proper tool selection, determination of optimum machining parameters (cutting speed, feed, depth of cut) or tool geometry (nose radius, rake angle, edge geometry, etc.) are necessary in order to obtain the desired surface finish comparable to grinding [6,7].

In order to decide the surface quality the statistical design of experiments (DOE) and statistical/mathematical model are used quite extensively. Statistical design of experiment refers to the process of planning the experimental so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusion [8]. Design and methods such as factorial design, Taguchi design and response surface methodology (RSM) are now widely used in place of one factor at a time experimental approach which is time consuming and exobitant in cost [9]. These methods have been used by some researchers for surface roughness [1], [4], [10]-[13], [15], [16], [19], [19]-[21], statistical method has been used for machinability [10]. Davim and Figueira [10] to investigate the machinability of cold work tool steel D2 heat treated to a hardness of 60 HRC. They concluded that with an appropriate choice of cutting parameters it is possible to obtain a surface roughness with Ra < 0.8 μm. This implies that hard machining is an alternative competitive process, which allows eliminating cylindrical grinding operation solutions. Sahin and Motorcu [11] developed the surface roughness model using response surface methodology in turning AISI 1050 hardened steels by CBN cutting tools under different conditions. Feed rate was found out to be the most significant factor on the surface roughness. Asiltürk and

Akkus [12] carried out hard turning experiment on hardened AISI 4140 steel (51HRC) with coated carbide insert using Taguchi orthogonal array for surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. A. Bhattacharya et al. [13] have investigated the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. The result showed a significant effect of cutting speed on surface roughness and power consumption, while the other parameters have not substantially affected the response.

In their experimental research work, Benga and Abrão [14] underlined that feed rate is most significant factor affecting surface finish than cutting speed for both CBN and ceramic inserts. Latter Ozel et al. [15] conducted a set of ANOVA and performed a detailed experimental investigation on the surface roughness and cutting forces in the finish hard turning of AISI H13 steel. Their results indicated that the effects of workpiece hardness, cutting edge geometry, feed rate and cutting speed on surface roughness are statistically significant. Singh and Rao [16] reported that the feed is the dominant factor determining the surface finish followed by nose radius and cutting velocity in finish hard turning of bearing steel (AISI 52100) using mixed ceramic inserts having different nose radius and different effective rake angles. The effect of the effective rake angle on the surface finish is less. But, the interaction effects of nose radius and effective rake angle are found to be also significant.

The present study is to investigate the influence of machining parameters under the surface roughness in dry turning of hardened EN24 steel with CVD (TiN+TiCN+Al_2O_3+ZrCN) multilayer coated carbide tool and determine the optimal levels of machining parameters for optimizing the surface roughness parameters (Ra and Rz) by employing Taguchi's orthogonal array design and utilizing analysis of variance (ANOVA). The relationship between the machining parameters (depth of cut, feed and cutting speed) and the performance measures i.e. surface roughness parameters (Ra and Rz) have been developed by using multiple second order regression models.

II. EXPERIMENTAL DETAILS

The work material was EN24 steel in the form of round bars with 60mm diameter and 120mm long were heat treated (quenching and tempering) to reach hardness of 47 HRC. EN24 is high tensile strength general engineering steel used in automotive and aircraft components, axles, arbors, extrusion liners, magneto drive coupling, shaft & wheels, pinions, etc. The chemical compositions of EN24 steel is given in Table I. The cutting tool was CVD (TiN/TiCN/Al_2O_3/ZrCN) multilayer coated carbide with an ISO designation of CNMG120408TN7015. TN7015 is a thick alumina-coated carbide grade with a moderately hard, deformation resistant substrate and it is CVD coated with TiCN under layer, followed by Al_2O_3 intermediate layer and ZrCN outer layer. The inserts were clamped on to tool holder with a designation of PCLNR2525M12. Combination of the insert and tool holder resulted in 6^0 clearance angle, 6^0 negative rake angle and 95^0 major cutting edge angle.

The experiment has been conducted to analyze the effect of depth of cut, cutting speed and feed on surface roughness (Ra and Rz). The experiments were carried out with three parameters at three levels each, as shown in Table II and experiments were planned according to Taguchi's L_{27} (3^{13}) Orthogonal array with 26 degree of freedom. The turning experiments were carried out in order to obtain experimental data in the dry condition on CNC lathe machine (Jobber XL, AMS India) which has a maximum spindle speed of 3500 rpm and a maximum power of 16kW. In attempts to evaluate the effects of machining parameters on surface roughness criteria (Ra and Rz) in hard turning by using experimental data, the working range was decided on the basis of data given in the hand book [17]. The surface roughness of the turned surface has measured using a portable Mitutoyo surface roughness tester (Taylor Hobson, Surtronic 25) in terms of arithmetic average roughness (Ra) and average maximum height of the roughness profile (Rz). Typically, grinding or honing surface-finishing processes yield surfaces with a Ra in the range of 0.1–1.6µm. We used 1.6µm as the control criterion for finish hard turning [18].

TABLE I
CHEMICAL COMPOSITION OF EN24 STEEL IN PERCENTAGE (%)

C	Mn	Cr	Mo	Ni	Si	Fe
0.39	0.77	1.1	0.17	1.55	0.38	Balance

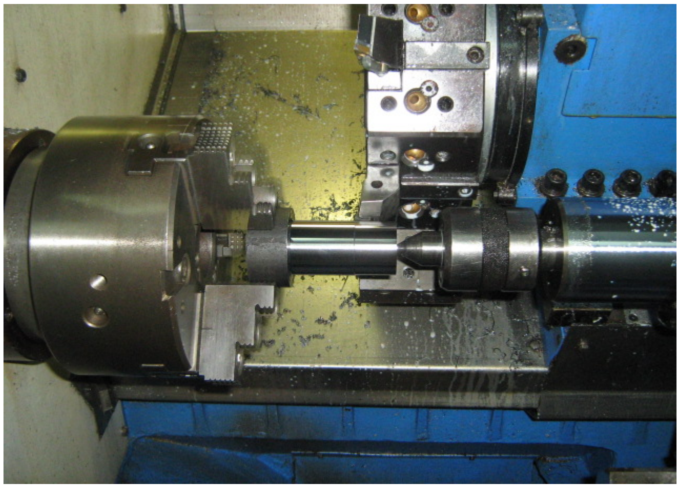

Fig. 1 View of cutting Zone

TABLE II
MACHINING PARAMETERS AND LEVELS

Parameters	Unit	Levels		
		1	2	3
Depth of Cut (D)	Mm	0.3	0.4	0.5
Feed (F)	mm/rev	0.1	0.15	0.2
Cutting speed(V)	m/min	90	120	150

III. RESULTS AND DISCUSSIONS

The plan of the experiment has been developed for assessing the influence of the cutting speed (V), feed (F) and depth of cut (D) on the surface roughness parameters (Ra and Rz). Table III illustrates the experimental results for surface roughness parameters. Minimal values of surface roughness criteria (Ra and Rz) were obtained at F = 0.1 mm/rev, V = 150 m/min and D = 0.4 mm (test number 12). Maximal values of surface roughness criteria (Ra and Rz) were registered at F = 0.2 mm/rev, V = 90 m/min and D = 0.4 mm (test number 16).

TABLE III
ORTHOGONAL ARRAY L_{27} OF TAGUCHI EXPERIMENT DESIGN AND EXPERIMENTAL RESULTS

Test No.	D	F	V	Ra(µm)	Rz(µm)
1	0.3	0.1	90	0.88	4.85
2	0.3	0.1	120	0.72	4.775
3	0.3	0.1	150	0.55	2.525
4	0.3	0.15	90	1.8	7.35
5	0.3	0.15	120	1.467	6.5
6	0.3	0.15	150	1.3	6.375
7	0.3	0.2	90	1.91	8.65
8	0.3	0.2	120	1.55	6.825
9	0.3	0.2	150	1.39	6.8
10	0.4	0.1	90	0.65	2.825
11	0.4	0.1	120	0.602	2.6
12	0.4	0.1	150	0.42	1.825
13	0.4	0.15	90	1.4	5.45
14	0.4	0.15	120	1.04	4.525
15	0.4	0.15	150	0.82	3.95
16	0.4	0.2	90	2.36	9.9
17	0.4	0.2	120	1.5	6.125
18	0.4	0.2	150	0.795	4.05
19	0.5	0.1	90	0.837	3.975
20	0.5	0.1	120	0.615	3.325
21	0.5	0.1	150	0.6	3.275
22	0.5	0.15	90	1.24	5.475
23	0.5	0.15	120	1.175	4.675
24	0.5	0.15	150	0.71	3.6
25	0.5	0.2	90	1.81	6.85
26	0.5	0.2	120	1.635	7.2
27	0.5	0.2	150	0.742	3.45

A. *Analysis of Variance (ANOVA)*

The experimental results are analyzed with analysis of variance (ANOVA), which is used for identifying the factors significantly affecting the performance measures. The results of the ANOVA with surface roughness Ra and Rz are shown in Table IV. This analysis was carried out for significance level of α=0.05, i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source to the total variation and indicating the degree of influence on the result.

From Table IV, it can be seen that, the F, V and D are significant sources on surface roughness parameters: arithmetic average roughness (Ra) and average maximum height of the roughness profile (Rz). The most significant parameter on the surface roughness criteria (Ra and Rz) is feed rate (F), which explains, respectively, 52.55% and 48.52% contributions of the total variation. The next largest contribution on Ra and Rz comes from the cutting speed (V) with the contributions 25.85% and 20.42% respectively. However, depth of cut (D) has least effect (4.91% and 16.25%) in producing roughness (Ra and Rz). The interactions (D×F), (F×V) and (D×V) are not statistical significant on surface roughness parameters.

The error contribution is 4.1% and 5.51% for tool surface roughness parameters, Ra and Rz respectively. As the percent contribution due to error is very small it signifies that neither any important factor was omitted nor any high measurement error was involved.

TABLE IV
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS (Ra)

Source	DOF	SS	MS	F-value	P	C (%)
(a) Analysis of variance for Ra						
D	2	0.32679	0.16340	4.81	0.043	4.91
F	2	3.49684	1.74842	51.45	0.000	52.55
V	2	1.72030	0.86015	25.31	0.000	25.85
D×F	4	0.21598	0.05400	1.59	0.267	3.24
F×V	4	0.48252	0.12063	3.55	0.060	7.25
D×V	4	0.13935	0.03484	1.03	0.450	2.10
Error	8	0.27186	0.03398			4.10
Total	26	6.65364				100
(b) Analysis of variance for Rz						
D	2	16.8239	8.4120	11.80	0.004	16.25
F	2	50.2453	25.1227	35.23	0.000	48.52
V	2	21.1395	10.5697	14.82	0.002	20.42
D×F	4	3.1026	0.7756	1.09	0.424	3.0
F×V	4	5.5558	1.3889	1.95	0.196	5.36
D×V	4	0.9763	0.2441	0.34	0.842	0.94
Error	8	5.7046	0.7131			5.51
Total	26	103.5481				100

DOF= Degree of freedom, SS= Sum of squares, MS= Mean squares, C= Contribution.

B. *Main effect of Plots*

Fig. 2 shows the main effect plot for surface roughness, Ra. In the plots, the x-axis indicates the value of each process parameter at two level and y-axis the response value. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum value of surface finish. The results show that with the increase in feed there is a continuous increase in surface roughness value. Here also, the main effect plot shows the decrease in roughness with increased cutting speed. Similar conclusions can be found in the literature [19], [20] and [21]. According to this main effect plot, the optimal conditions for surface roughness are: feed at level-1(0.10mm/rev) and cutting speed at level-3 (150m/min).

Fig. 3 shows the main effect plot for surface roughness, Rz. Surface roughness increases with increased feed. Further, the surface finish improves with increasing the cutting speed. Therefore, to obtain a low value of surface should be set at high cutting speed (150m/min), low feed (0.10mm/rev) and depth of cut at 0.4mm.

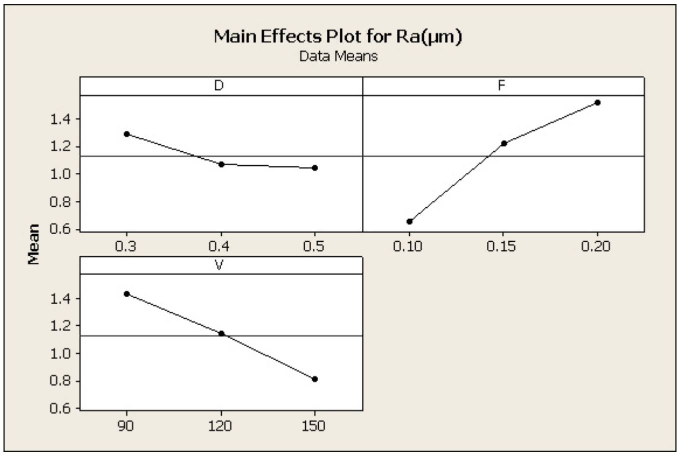

Fig. 2 Main effects plot for surface roughness (Ra)

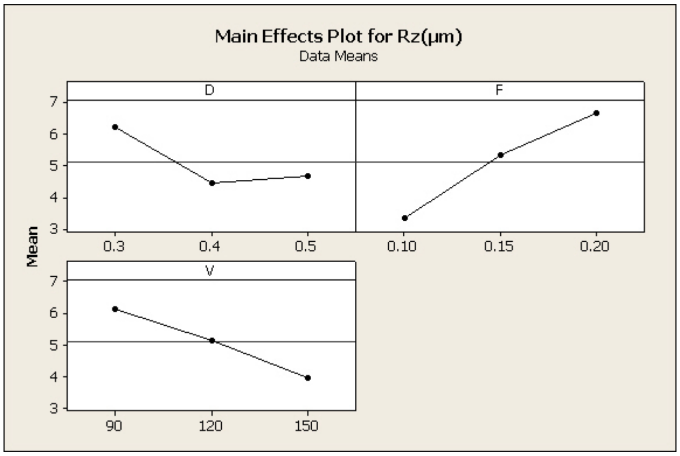

Fig. 3 Main effects plot for surface roughness (Rz)

C. *Prediction of Optimal Design*

When surface roughness (Ra) is considered from Table VI, an estimated average when the two most significant factors are at their better level is

$$\mu_{R_a} = \overline{F}_1 + \overline{V}_3 - \overline{T}_{R_a} \quad \text{(from Table III, } \overline{T}_{R_a} = 1.1303\text{)}$$

$$= (0.6527 + 0.8141) - 1.1303 = 0.3365$$

$$\text{CI} = \sqrt{\frac{F_{95\%.1,\text{DOF error}} \times V_{\text{error}}}{\eta_{\text{eff}}}}$$

Where $\eta_{\text{eff}} = \frac{N}{1 + \text{DOF associated to that level}} = \frac{27}{1+2+2} = 5.4$

$F_{95\%.1,\,8} = 5.32$ and $V_{\text{error}} = 0.03398$ (from Table IV)

Thus, $\text{CI} = \sqrt{\frac{5.32 \times 0.03398}{5.4}} = 0.1829$

Finally, the estimated average with the confidence interval at 95% confidence (when the two most significant factors are at their better level) is

$$(0.3365-0.1829) \leq \mu_{R_a} \leq (0.3365+0.1829)$$

$$0.1536 \leq \mu_{R_a} \leq 0.5195$$

Similarly, when surface roughness (Rz) is concerned, estimated average is at F_1V_3 level. Then,

$$\mu_{R_z} = \overline{F}_1 + \overline{V}_3 - \overline{T}_{R_z} \quad \text{(from Table III, } \overline{T}_{R_z} = 5.101\text{)}$$

$$= (3.331 + 3.983) - 5.101 = 2.213$$

$F_{95\%.1,\,8} = 5.32$, $\eta_{\text{eff}} = 5.4$, $V_{\text{error}} = 0.7131$ (from Table IV)

Thus, $\text{CI} = \sqrt{\frac{5.32 \times 0.7131}{5.4}} = 0.838$

Finally, the estimated average with the confidence interval at 95% confidence (when the two most significant factors are at their better level) is

$$(2.213-0.838) \leq \mu_{R_z} \leq (2.213+0.838)$$

$$1.375 \leq \mu_{R_z} \leq 3.051$$

TABLE V
MEAN VALUES OF SURFACE ROUGHNESS (Ra &Rz) AT DIFFERENT LEVELS

Level	Roughness Ra (µm)			Roughness Rz (µm)		
	$\overline{D}$	$\overline{F}$	$\overline{V}$	$\overline{D}$	$\overline{F}$	$\overline{V}$
1	1.2852	**0.6527**	1.4319	6.211	**3.331**	6.147
2	1.0652	1.2169	1.1449	4.444	5.322	5.172
3	1.0404	1.5213	**0.8141**	4.647	6.650	**3.983**
Delta	0.2448	0.8687	0.6178	1.767	3.319	2.164
Rank	3	1	2	3	1	2

Bold values indicate the levels of significant parameters for which the best result obtained and the optimal design is calculated.

D. *Correlation*

Multiple second order regression model have been implemented at 95% confidence level to obtain the correlation between the machining parameters (depth of cut , feed and cutting speed) and the measured surface roughness parameters, Ra and Rz. The obtained equation was as follows:

$$Ra = -1.9366 - 6.0036D + 43.7467F + 0.0206V + 9.7611D^2 - 51.9556F^2 - 0.000V^2 - 9.4167D \times F - 0.0135D \times V - 0.1309F \times V \quad (R^2 = 90.97\%)$$

$$Rz = -7.312 - 76.889D + 149.861F + 0.047V + 98.472D^2 - 132.778F^2 - 0.000V^2 - 74.167D \times F - 0.012D \times V - 0.393F \times V \quad (R^2 = 90.82\%)$$

The layer value of R^2 is always desirable. This confirms the suitability of the multiple regression equation and correctness of the calculated constants. To test statistical significance of 2nd order model, analysis of variance table is constructed and shown in Tables VI and VII for both surface roughness parameters Ra & Rz respectively. F-ratio is also the important index to check the adequacy of model, where calculated F-value should be greater than F-table value. From Table VI and Table VII, second order model is found to be statistically significant as P-value (probability of significance) is less than 0.05 and F calculated value is greater than F-table value

(2.49). It is revealed that terms mentioned in the model have significant effects on the responses.

TABLE VI
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS (Ra) 2nd ORDER MODEL

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Regression	9	6.05270	6.052697	0.672522	19.02	0.000	Significant
Linear	3	5.38266	0.621567	0.207189	5.86	0.006	
Square	3	0.16127	0.161269	0.053756	1.52	0.245	
Interaction	3	0.50877	0.508765	0.169588	4.80	0.013	
Residual Error	17	0.60095	0.600946	0.035350			
Total	26	6.65364					

TABLE VII
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS (Rz) 2nd ORDER MODEL

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Regression	9	94.045	94.0453	10.44948	18.69	0.000	Significant
Linear	3	81.661	12.3422	4.11408	7.36	0.002	
Square	3	6.548	6.5478	2.18260	3.90	0.027	
Interaction	3	5.837	5.8366	1.94552	3.48	0.039	
Residual Error	17	9.503	9.5028	0.55899			
Total	26	103.548					

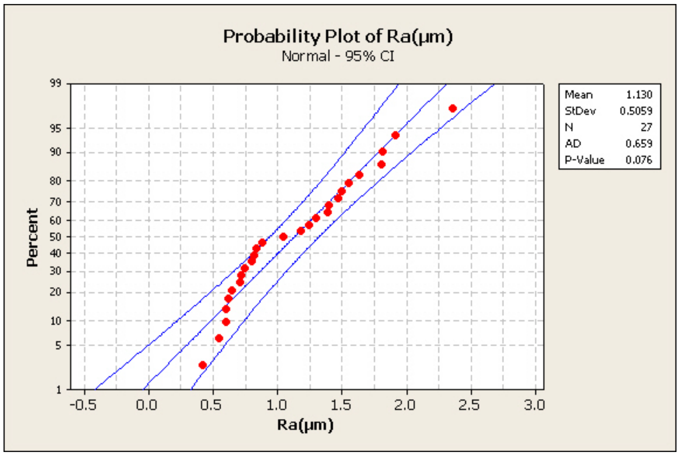

Fig. 4 Normal probability plot of surface roughness (Ra)

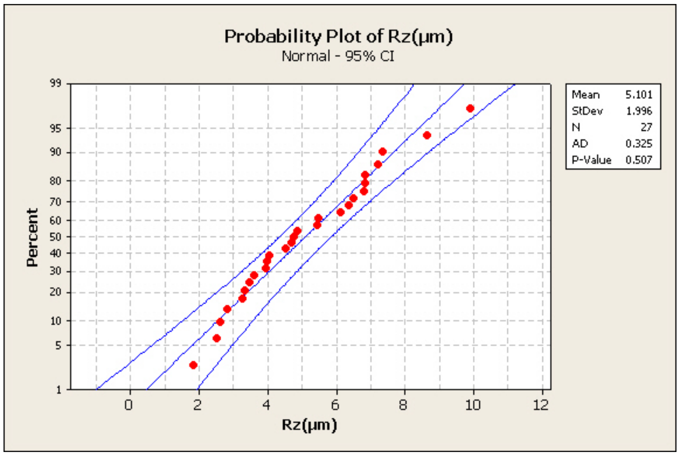

Fig. 5 Normal probability plot of surface roughness (Rz)

Inspection of some diagnostic plots of the model was done to test the statistical validity of the models. The residuals could be said to follow a straight line in normal plot of residuals implying that the errors were distributed normally, shown in Fig. 4 and Fig. 5 for roughness parameters Ra and Rz respectively. From figure it can be concluded that all the values are with in the CI level of 95%. Hence, these values yield better results in future prediction.

IV. CONCLUSIONS

The following conclusions are derived during turning of hardened EN24 steel with CVD multilayer coated carbide insert. Also doing experimentation the effect of various machining parameters on surface roughness are studied.

1. Taguchi orthogonal array design have introduced to evaluate the effect of machining parameters on the surface roughness. Also the optimal machining conditions have been determined to minimize the surface roughness during turning operation.
2. The research finding along with the various mathematical analysis will provide the effective guidline to select machining parameters for achieving desired surface roughness during turning operation of hardened steel using coated carbide insert.
3. Feed was found to be most significant parameter for the workpiece surface roughness, Ra and Rz with a percent contribution of 52.55% and 48.52 respectively. Cutting speed was found to be the next significant parameter for Ra and Rz with contribution of 25.85% and 20.42% respectively. Depth of cut was found to be a significant parameter for Rz with contribution of 16.25% whereas, depth of cut a negligible influence in case of Ra.
4. The surface roughness is within recommended range of hard turning i.e. Ra value within 1.6 µm for multilayer ZrCN coated carbide inserts. From the study, it is evident that, the multilayer coated carbide inserts have performed well at a combination of cutting speed (150 m/min), feed (0.10 mm/rev) and depth of cut (0.4 mm).
5. The predicted optimal range of workpiece surface roughness parameters, Ra and Rz are $0.1536 \leq \boldsymbol{\mu}_{\mathbf{R_a}} \leq 0.5195$ and $1.375 \leq \boldsymbol{\mu}_{\mathbf{R_z}} \leq 3.051$ respectively.
6. The regression models of workpiece surface parameters, Ra and Rz presented high determination of coefficient (R^2 = 0.9097 and 0.9082) close to unity) explaining 90.97% and 90.82% of the validity in the response which indicates the goodness of fit for the model and high significance of model.

V. REFERENCES

[1] J.S. Shaik and K.R.Babu, “Prediction of surface roughness in hard turning by using Fuzzy logic,”*International Journal of Emerging trends in Engineering and Development*, Vol.5, Issue 2, pp. 38-49, 2012.

[2] P. Marimuthu and K. Chandrasekaran, “Experimental study on stainless steel for optimal setting of machining parameters using Taguchi and Neural network,” *ARPN J. of Engineering and Applied Sciences*, Vol. 6, No. 10, pp. 119-127, 2011.

[3] S.R. Das, D. Dhupal and A. Kumar, “Analysis of Surface Roughness in Turning of Hardened AISI 4340 Steel with Coated Carbide Inserts,” *International Journal of Pure and Applied Research in Engineering and Technology*, Vol.1, Issue 5, pp. 25-36, 2012.

[4] D.I. Lalwani, N.K. Mehta, N, and 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, No. 1,pp. 167-179, 2008.

[5] T. Hodgson, P.H.H. Trendler and G.F. Micheletti, “Turning hardened tool steels with cubic boron nitride insert”, *Annals of the CIRP-Manufacturing Technology*, 1981; 30(1): 63-66.

[6] D. Gillibrand, M. Sarwar and C.T. Pierce, “The economic benefit of finish turning with coated carbide”, *Surface and Coatings Technology*,”Vol. 86, No. 2, pp. 809-813, 1996.

[7] M.C. Shaw, “*Metal cutting principles*”' Oxford University Press, New York, 2005.

[8] D.C. Montgomery, “*Design and Analysis of Experiments*,” John Wiley & Sons Inc, 2001.

[9] M.Y. Noordin, V.C. Venkatesh, S. Sharif, S. Elting and 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, pp. 46–58, 2004.

[10] J.P. Davim, and L. Figueira, “Machinability evaluation in hard turning of cold work tool steel (D2) with ceramic tools using statistical techniques,”*Journal of Materials and Design*, Vol. 28,pp. 1186–1191, 2007.

[11] Y. Sahin and A.R. Motorcu, “Surface roughness model in machining hardened steel with cubic boron nitride cutting tool,” *Int. J. Refract. Metals Hard Mater*., Vol. 26, pp. 84–90, 2008.

[12] I. Asiltürk and H. Akkus, “Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method,” *Measurement*, Vol. 44, pp. 1697–1704, 2011.

[13] A. Bhattacharya, S. Das, P. Majumder and A. Batish. “Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA,”*Prod. Eng. Res. Devel*, Vol. 3, pp. 31–40, 2009.

[14] G.C. Benga and A.M. Arabo, “Turning of hardened 100Cr6 bearing steel with ceramic and PCBN cutting tools,” *J. Mater. Process. Technol.*,Vol. 143, pp. 237–241, 2003.

[15] T. Özel, T.K. Hus and E. Zerne, “Effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and forces in finish turning of hardened AISI H13 steel,” *Int. J. Adv. Manuf. Technol.,* Vol. 25, pp. 262–269, 2005.

[16] D. Singh and P.V. Rao, “A surface roughness prediction model for hard turning process,” *Int. J. Adv. Manuf.*,Vol. 32, No. (11–12), pp. 1115–1124, 2007.

[17] E. Isakov, “*Cutting data for turning steel*,”Industrial press, New York, 2009.

[18] M.Y. Noordin, Y.C. Tang and D. Kurniawan, “The use of TiAlN coated carbide tool when finish machining hardened stainless steel,”*International J. of Precision Technology*, Vol. 1, No. 1, pp. 21-29, 2007.

[19] J.P. Davim, “A note on the determination of optimal cutting conditions for surface finish obtained in turning using design of experiments,” *Journal of Materials Processing Technology*, Vol. 116, Issues 2–3, pp. 305–308, 2001.

[20] R. Suresh, S. Basavarajappa and G.L. Samuel, “Some studies on hard turning of AISI 4340 steel using multilayer coated carbide tool,” *Measurement*, Vol. 45, Issue 7, pp. 1872–1884, 2012.

[21] E. Aslan, N. Camuscu and B. Bingoren, “Design optimization of cutting parameters when turning hardened AISI 4140 (63 HRC) with Al_2O_3+TiCN mixed ceramic tool,” *Mater. Des.*,Vol. 28, pp. 1618–1622, 2007.