Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.12 n.57, p. 529-534. January/February, 2026.
DOI: https://doi.org/10.5935/jetia. v12i57.3171

RESEARCH ARTICLE OPEN ACCESS

ANALYSIS OF S.S.43100 BY TURNING OF TI16ZR PVD COATED TOOL INSERTS AND OPTIMIZATION OF SURFACE ROUGHNESS USING TAGUCHI METHOD

Nisha.N.Jadeja*[1], Sanjay.H.Zala[2], Hirendra.G.Vyas[3]

[1, 2, 3]Mechanical Engineering Department, Government Engineering College Bhavnagar, -360004,Gujarat, India

[1]https://orcid.org/0000-0001-9582-7059, [2]https://orcid.org/0009-0004-9108-8083, [3]https://orcid.org/000-0002-4488-8596

Email: *nishazala1979@gmail.com, shzala.mech@gecbhavnagar.ac.in, hgv135@gmail.com

ARTICLE INFO

Article History
Received: December 19, 2025
Revised: December 20, 2025
Accepted: January 1, 2026
Published: January 31, 2026

Keywords:
Hard turning;
Hardened alloy steel;
The Surface temperature of the workpiece.
Taguchi Method

ABSTRACT

The performance of PVD coated carbide inserts for various machinability aspects during machining of hardened alloy steel AISI 43100, under a dry cutting environment. Spindle speed, feed, and depth of cut were considered as major governing parameters. Workpiece surface roughness, machining forces (Fx, Fy, Fz) were taken as measures of the performance estimation of PVD coated (Ti16Zr)cutting inserts in this work. All the input variables were observed to have influence over workpiece surface roughness and cutting forces in the case of coated carbide inserts. In the current research, the effects of machining parameters on the dry turning rotation of the SS43100 with uncoated and Ti16Zr coated tool inserts have been investigated and the optimal machining specifications are computed using the Taguchi L27 experimental design. The Regression analysis with regression equations is mentioned and inspected the significance of individual factors for responses. The machining operations can be performed at a higher spindle speed(250r.p.m.,450 r.p.m.,650 r.p.m.),feed (0.085mm/rev,0.2 mm/rev, 0.45 mm/rev), depth of cut(0.2mm,0.3mm,0.4mm) without compromising results when cermets inserts are used. Carbide exceeded the performance on cutting force and workpiece surface roughness, though carbides outperformed regarding feed and cutting force(FY). The depth of cut was found to be the most significant when feed and cutting forces were concerned, while it was true for radial force using carbides. Speed affected workpiece surface roughness the most. Feed was the most important parameter while the surface roughness of the workpiece was taken into account.

I. INTRODUCTION

According to Pal et al. [1] machining of work piece material having hardness up-to 45 HRC is treated as soft machining. On the other hand, machining of work piece having hardness in the range of 45-70 HRC is considered under hard machining . They have done turning operations on AISI 4340 steels of hardness values 35, 45, 55 HRC with the help of mixed alumina ceramic tools. Harder work piece resulted in higher cutting forces, higher tool-chip interface temperature but lower surface roughness. Surface roughness was more prominently affected by feed rates whereas radial forces by the depth of cut. Cutting speed and depth of cut were more significant when it came to average chip-tool interface temperature. This finding is in line as per the experiments done by Chinchanikar and Choudhury [2] on AISI 4340 steel with single-layer TiAlN coated (PVD) and multi-layer TiCN/ Al2O3/ TiN coated (CVD) carbide tools [3]. They have seen the chip-tool interface temperature to increase rapidly with cutting speed, slightly with feed but to remain almost same with the depth of cut. Moreover, the temperature was found to be greater in case of CVD coated tools than PVD coated ones.

They have also developed a mathematical model to predict chip-tool interface temperature which was valid over a wide range of cutting conditions[4]. D'Errico et al. [5] used uncoated and TiN, Ti(C,N) coated cermet inserts with and without chamfered edge in continuous and interrupted turning operation of SAE 1045 steel. From the experimental results they concluded that PVD coated inserts without chamfered edge performed well only in continuous turning rather than interrupted turning [6]. Furthermore, they stated that tools with chamfered edge are better for interrupted turning where the high depth of cut is involved. There was no significant effect of coating on tool life irrespective of their cutting edges in interrupted turning. Suresh R [7] worked on the capabilities of TiN coated cermet tools on high speed machining of austenitic stainless steel. SEM images discovered that the failure of cutting edges of cermet tools started with micro-cracks which grew gradually to cause the tool failure due to low fracture toughness.

It gave satisfactory results to use cermet tools while machining at low speed, feed and depth of cut because of good surface finish and long tool life. Selvaraj D. Philip [8] the authors recommended to keep the cutting speed under 300 m/min, feed rate under 0.2 mm/rev and depth of cut under 0.3 mm to have a satisfactory tool life. The similar point of view was shared by Noordin et al. [9] who found the tool life of TiCN based cermet inserts to be highest at low cutting speed and feed rate. [10] However, the performance of coated carbides was superior at medium and high cutting speed and feed. Also, from the experimental results, they observed that with an increase in negative side cutting edge angle, tool life increased. But, Sahoo A. et al. [11] showed there is a decrease in tool life and surface finish with increasing negative rake angle. This was due to increase in cutting force and excessive heat generation.

[12]Tool life was also dependent on the speed of cutting. At high speed, tool life was shorter but at the same time, the surface finish was found out to be finer. H. Hong et al. [13] investigated on the wear mechanisms in the end milling with wet machining operation of steel and titanium alloys steel using TiN coated carbide and uncoated cermet inserts. Håkan Tahoor's, H [14] They assessed that the flank wear at the flank face predominantly controlled the tool wear phenomenon. Besides, they observed that the time taken by coated carbides to initiate cracking and fracturing is more than that of uncoated cermet. [15] They also concluded with low cutting parameters, uncoated cermet's experience more uniform and gradual wear compared to coated carbides. Autor performed various experiments by using Taguchi method on material SS431and optimize surface roughness by PVD coated TiZr tool [16].

II. MATERIALS AND METHODS

Selection of optimal parameters was carried out by performed number of pilots experiments, discussion with manufacturing industry experts. Range finalized for final experiments shown in table 1 . Input parameters are cutting speed, feed and depth of cut. Output parameter is surface roughness (Ra) . These experiments were performed on HMC Lathe machine MONO 200XL . Std. CNC machine capacity has turning Dia. Mm 200, Swing Over Bed Mm 500 , Max. Turning Length Mm 700, Dist. Between Center Mm 750.

Figure 1: ITI surf test RS 232" (make: ITI, India) surface roughness tester.
Source: Authors (2026).

Coated carbides are Tungsten, Cobalt based, designated by CNMG120408EN The shape of the inserts was rhombic (80º point angle) specific chip breaker geometry which was mounted on tool holder of ISO designation PSBNR 2525M12 as shown in Fig. The tool holder has the following cutting geometries i.e. clearance angle = 0º, back and side rake angle = -6º, entering angle = 75º, point angle = 90º and nose radius = 0.8 mm.Roughness Ra value of machined sample is measured using "ITI surf test RS 232" (make: ITI, India) surface roughness tester. Cutting inserts were Tungsten carbide. PVD coating method was used for coating inserts by Calo technique. Researchers were selected different combination of material, here Ti16Zr used for coating. Hardness of this material and anti corrosion properties are more affected for surface finish for parent material.

Table 1: Selection of Optimal parameters for final Experiments.

Sr.No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Cutting speed	r.p.m.	250	450	650
2	Feed	mm/rev	0.085	0.2	0.45
3	Depth of cut	mm	0.2	0.3	0.4

Source: Authors (2026).

III. RESULTS AND DISCUSSIONS

Parameters. Developed models are used for prediction and validation (confirmation) experiments. In confirmation experiments predicted results are compared with experimental results. With the help of regression equation obtain best optimum value for surface roughness from output response . From the conformation experiments for the surface roughness, we select the set of parameters for first experiment are cutting speed 650r.p.m. feed .45mm/rev and depth of cut .3mm. The experimental value obtain are 1.412µ and 2.321µ while predicted surface roughness value is 1.039µ. Error identified for this first set of experiment is 0.8275%. We have repeated this procedure for remaining three sets of experiments and identified error -0.0345%, 0.543% and 1.079%. At the end of experiments for surface roughness we conclude that the errors are less than 10% which shows that the confirmation tests results are adequate with cutting speed 650 r.p.m , feed 0.45mm/rev and depth of cut 0.3 mm.for optimum value of surface roughness.

Table 2: Taguchi Analysis: RA versus Cutting Speed, Feed, Depth of cut.

Sr.no	Run order	Cutting speed	Feed	Depth of cut	RA	SNRAI
1	5	250	0.2	0.3	2.01	-6.0639211
2	9	250	0.45	0.4	2.19	-6.8088823
4	19	650	0.085	0.4	1.62	-4.1903003
5	21	650	0.085	0.4	1.36	-2.6707782
6	27	650	0.45	0.3	1.18	-1.4376401
7	14	450	0.2	0.4	1.86	-5.3902589
8	1	250	0.085	0.2	2.95	-9.3964403
9	10	450	0.085	0.3	1.98	-5.9333038
10	16	450	0.45	0.2	1.31	-2.3454259
11	20	650	0.085	0.4	1.47	-3.3463467
12	11	450	0.085	0.3	1.91	-5.6206673
13	12	450	0.085	0.3	1.52	-3.6368718
13	26	650	0.45	0.3	1.12	-0.9843605
14	22	650	0.2	0.2	1.28	-2.1441994
15	2	250	0.085	0.2	2.45	-7.7833217
16	8	250	0.45	0.4	2.23	-6.9660973
17	18	450	0.45	0.2	1.81	-5.1535715
18	24	650	0.2	0.2	1.19	-1.5109392
19	6	250	0.2	0.3	2.21	-6.8878455
20	4	250	0.2	0.3	2.45	-7.7833217
21	17	450	0.45	0.2	1.7	-4.6089784
22	25	650	0.45	0.3	0.9	0.91514981
23	13	450	0.2	0.4	1.32	-2.4114786
24	23	650	0.2	0.2	1.22	-1.7271966
25	15	450	0.2	0.4	1.74	-4.810985
26	3	250	0.085	0.2	2.5	-7.9588002
27	7	250	0.45	0.4	2.06	-6.2773444

Source: Authors (2026).

Table 3: Regression Analysis: RA versus Cutting Speed, Feed, Depth of cut Analysis of Variance.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	5.74983	84.38%	5.74983	1.91661	41.42	1.000
Cutting Speed	1	5.23801	76.87%	5.23801	5.23801	113.21	0.000
Feed	1	0.49440	7.26%	0.49440	0.49440	10.69	0.003
Depth of cut	1	0.01742	0.26%	0.01742	0.01742	0.38	0.545
Error	23	1.06416	15.62%	1.06416	0.04627		
Lack-of-Fit	5	0.29616	4.35%	0.29616	0.05923	1.39	0.275
Pure Error	18	0.76800	11.27%	0.76800	0.04267		
Total	26	6.81399	100.00%				

Source: Authors (2026).

Table no 2 shown Regression analysis of RA done with the help of MINITAB software. Total no of degree of freedom were 26. Maximum significant factor was cutting speed. Secondary factor is feed which have p-value less than 0.005.

Table 4: Model Summary.

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.215099	94.38%	92.35%	1.44360	98.81%

Source: Authors (2026).

Regression R-sq(adj) and R-sq (pred) values are displayed in the model summary. Greater than 90% for the coefficient of determination R-sq value unambiguously shows that the models are suitable for use in the future.

Very little variation exists between R-sq(pred) and R-sq(adj). Table 3 represents a safe number for the coefficient of determination indicates that the model created for surface roughness using the combinations of the input parameter sets is sufficient

RA=3.285 - 0.002697 Cutting Speed - 0.888 Feed - 0.311 Depth of cut

Regarding PVD coated (Ti16Zr) carbide tool inserts, regression equation models are created independently for each of the output responses. obtained the optimal values for additional input parameter combinations. Experiments involving prediction and validation (confirmation) employ developed models. Predicted and experimental findings are contrasted in confirmation experiments. Obtain the greatest possible value for surface roughness from the output response with the aid of the regression equation.

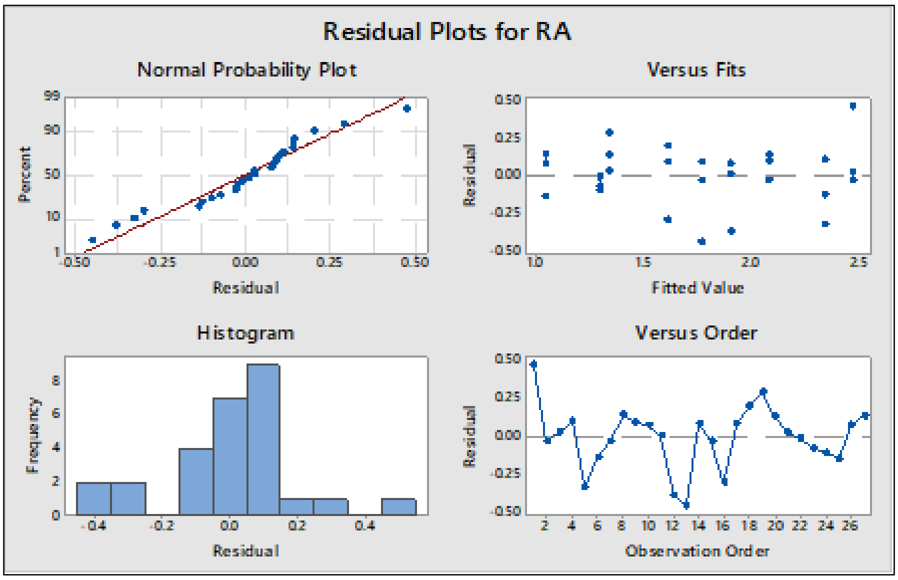

Figure 2: Residual plots for Ra.
Source: Authors (2026).

In above residual shows number of combinations which have interaction plots in between various input responses. Total combination of interactions are shown in graphically in above figure 2.

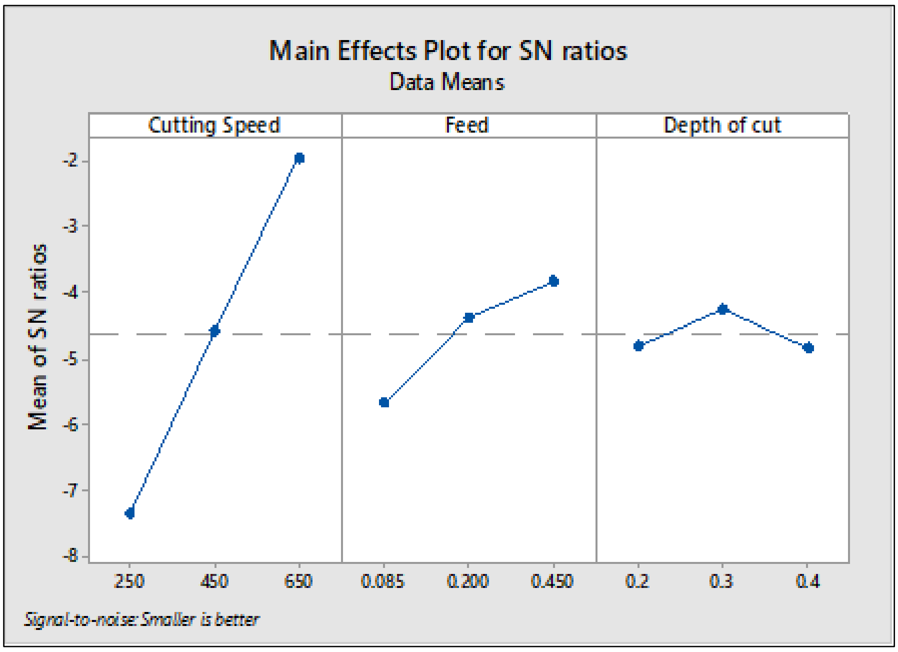

Figure 3: Main effects plot for signal to noise ratio for RA.
Source: Authors (2026).

From figure 3 shows that best value for surface roughness RA is obtained at 250 r. p.m. cutting speed , feed is 0.085 mm/rev, depth of cut is 0.3 mm experiments cutting speed is most dominant parameter which affects the value of surface roughness. Martensitic AISI SS43100 is hard to cut material if we increase cutting speed then the friction increased in between tool and work piece material. With this temperature increase at zone of machining also so it is directly affect the value of surface roughness. In pilot experiments the effects of feed is very important it was main factor for machining, now cutting speed is most dominant factor for machining. These graphical analysis of different parameters were shown in above fig.3. Table no 4 shows confirmation experiments for roughness.

Table 5: Confirmation experiments for RA.

Sr. No.	Cutting speed	Feed	Depth of cut	Exp.RA	Pred RA	Mean RA	ERROR (mean-pred)
R1	650	0.45	0.3	1.412	1.039	1.8665	0.8275
R2	650	0.45	0.3	2.321			
R1	250	0.085	0.2	2.365	2.473	2.4385	-0.0345
R2	250	0.085	0.2	2.512			
R1	250	0.2	0.3	2.684	1.589	2.132	0.543
R2	250	0.2	0.3	1.58			
R1	650	0.085	0.4	2.401	1.332	2.411	1.079
R2	650	0.085	0.4	2.421			

Source: Authors (2026).

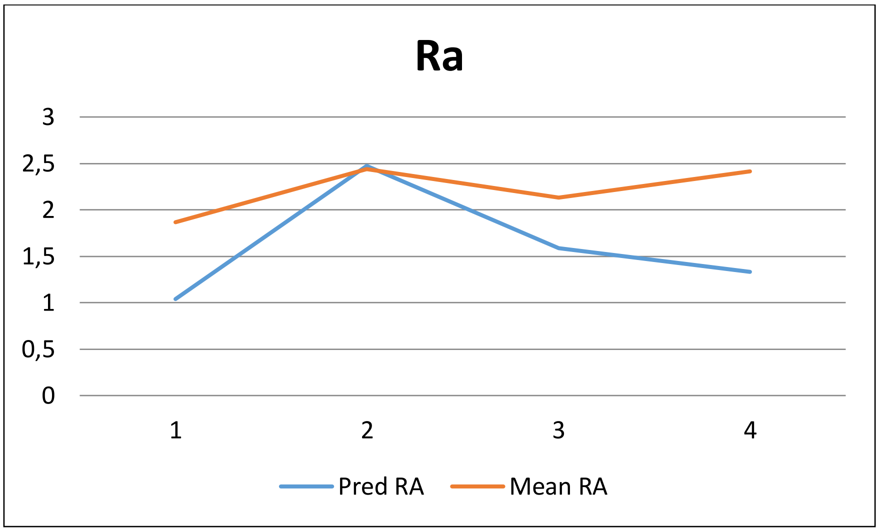

Figure 5: Comparison between experimental and predicted values of surface roughness.
Source: Authors (2026).

IV. CONCLUSIONS

From above fig. 5 shows comparison between Predicated value of RA and Mean value of RA the result table of ANOVA demonstrates that the most important surface roughness factors (RA) Models of correlation for surface roughness are developed by Ti16Zr-coated carbide inserts. Final experiments have been carried out L27 for the individual parameters, the determination of coefficient value has been found for surface roughness is 92.35%.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Methodology: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Investigation: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Discussion of results: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Writing – Original Draft: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Writing – Review and Editing: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Resources: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Supervision: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.
Approval of the final text: Nisha.N.Jadeja, Sanjay.H.Zala, Hirendra.G.Vyas.

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