OPTIMIZATION OF PROCESS PARAMETERS IN TURNING OF AISI202 AUSTENITIC STAINLESS STEEL

M. Kaladhar[1], K. Venkata Subbaiah[2], Ch. Srinivasa Rao[2] and K. Narayana Rao[3]
[1]Department of Mechanical Engineering, Anil Neerukonda Institute of Technology, Visakhapatnam, Andhra Pradesh, India
[2]Department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India
[3]Department of Mechanical Engineering, Government Polytechnic, Visakhapatnam, Andhra Pradesh, India
E-Mail: kaladhar2k@gmail.com

ABSTRACT

This paper deals with the optimization of machining parameters in turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. During the experiment, process parameters such as speed, feed, depth of cut and nose radius are used to explore their effect on the surface roughness (R_a) of the work piece. The experiments have been conducted using full factorial design in the Design of Experiments (DOE) on Computer Numerical Controlled (CNC) lathe. Further, the analysis of variance (ANOVA) was used to analyze the influence of process parameters and their interaction during machining. From the analysis, it is observed that the feed is the most significant factor that influences the surface roughness followed by nose radius. An attempt has been made to generate to prediction models for surface roughness. The predicted values are confirmed by using validation experiments.

Keywords: optimization, stainless steel, machining, tool wear, turning, surface roughness, CVD coating.

1. INTRODUCTION

Surface roughness has become the most significant technical requirement and it is an index of product quality. In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. Nowadays, manufacturing industries specially concerned to dimensional accuracy and surface finish. In order to obtain optimal cutting parameters, manufacturing to obtain optimal cutting parameters, manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity due to sub-optimal use of machining capability this causes high manufacturing cost and low product quality [1].

Hence, there is need for a systematic methodological approach by using experimental methods and statistical/mathematical models. The design of experiments (DOE) is an efficient procedure for the purpose of planning experiments. Further the data can be analyzed to obtain valid and objective conclusions.

Several experimental investigations have been carried out over the years in order to study the effect of cutting parameters, tool geometries on the work pieces surface integrity using several work pieces. Tool geometry plays an important role in machining. It is mentioned that the nose radius will affect the performance of the machining process [24]. Nose radius is a major factor that affects the surface finish of work piece. It is proved that high values of nose radius causes rough surface with high value of run out [20]. But very few researchers have studied the interaction effect of nose radius [19]. The effect of nose radius on the surface roughness was investigated by Ravindra [19], A. Saad kariem [20], Kishawy [12], Chou [8], Sundaram [21], Lambert [14] and B. hattacharya *et al*. [6].

A high work hardening rate, low thermal conductivity and resistance to corrosion are the characteristics of austenitic stainless steels (Groover, 1996). It was reported that austenitic stainless steels come under the category of difficult to machine materials [1].

Little work has been reported on the determination of optimum machining parameters when machining austenitic stainless steels [13]. Lin [16] investigated surface roughness variations of different grades of austenitic stainless steel under different cutting conditions in high speed fine turning. Ranganathan and Senthilvalen [18] developed a mathematical model for process parameters on hard turning of AISI 316 stainless steel. Surface roughness and tool wear was predicted by Regression analysis and ANOVA theory. Anthony xavior and Adithan [4] determined the influence of different cutting fluids on wear and surface roughness in turning of AISI304 austenitic stainless steel. Ibrahim Ciftci [10] conducted the experiments to Machine AISI 304 and AISI 316 austenitic stainless steels using CVD multi-layer coated cemented carbide tools. The results showed that cutting speed significantly affected the machined surface roughness values. Cebeli ozek, *et al*., [7] investigated to determine surface roughness, tool wear and tool- chip interface temperature in turning of AISI 304.

Machining of austenitic stainless steels result Poor surface finish and high tool wear [1]. Vishal Parashar *et al*., [23] conducted investigation to machine Wire Cut Electro Discharge Machining of 304L stainless steels to optimize surface roughness using Taguchi Dynamic Experiments concept. Lanjewar *et al*., [15] conducted experiments to evaluate the performance of AISI304 steel on auto sharpening machine by using Taguchi method. Results revealed that tools shape and feed are significant factors. Empirical models for tool life, surface roughness and cutting force are developed for turning of AISI302 developed by Al-Ahmari [2]. Multiple regression analysis techniques, Response surface methodology and computational neural networks were used to predict models of process functions. A considerable work on 300 series austenitic stainless steel has been reported.

AISI 202 austenitic stainless steel finds it application in general industrial and process-industry machinery and equipment, electrical machinery/equipment, automotive industry, Structural, bus body etc., [11]. But, it is found that no work has been reported in the literature on optimization of process parameters in turning of AISI 202 austenitic stain less steel. In the present investigation, full factorial experiment has been employed to determine the best combination of the machining parameters such as cutting speed, feed, depth of cut and nose radius to attain the minimum surface roughness and the predictive models obtained for surface roughness. The predicted and measured values are fairly close to each other.

2. MATERIALS AND METHODS

2.1 Work piece material

The work piece material used for present work was AISI 202 austenitic stainless steel. There are two types of austenitic stainless steel: 300-series and 200-series. Most stainless steel used around the world is of the 300-series type. The 200 series stainless steels have become popular in the Asian continent, particularly as an alternative to 300 series in view of increase in nickel prices. However, this has not been without problems. The 200 series are non-magnetic and austenitic. Hence, it is very difficult to distinguish from widely used 300 series of stainless steel, which are also non-magnetic. One such family of stainless steels is the 200-series. The 200-series are a technically valid family of stainless steels but, like all stainless steel stainless steels they have their limitations [5]. The chemical composition of AIS202 is given in Table-1.

Table-1. Chemical composition (wt %) of AISI 202.

Cr (%)	**Ni** (%)	**Mn** (%)	**N** (%)
17.0	4.0	7.5	0.25

2.2 Cutting inserts and cutting conditions

Coated carbide tools have shown better performance when compared to the uncoated carbide tools [17]. For this reason, commonly available Chemical Vapor Deposition (CVD) of Ti (C, N) +Al_2O_3 coated cemented carbide inserts of 0.8 and 0.4mm as nose radius are used in the present experimental investigation. The Process parameters and levels used in the experiment, experimental set up and conditions are given in the Tables 2 and 3.

Table-2. Experimental set up and conditions.

Machine tool : ACE Designer LT-16XL CNC lathe, 7.5 kW (10 hp) and 4000 rpm, India.
Work specimen material : AISI 202 austenitic stainless steel
Size : Φ25 mm x 70mm
Cutting t inserts (SECO make) : CNMG 120408, CNMG 120404
Tool material (TP-2500). : CVD coated cemented carbide
Two holders : PCLNL 252570012(ISO specification)
Environment : Dry machining

Table-3. Process parameters and levels used in the experiment.

Code	**Process parameters**	**Level** (-1)	**Level** (+1)
A	Cutting speed (m/min)	111	200
B	Depth of cut (mm)	0.25	0.75
C	Feed (mm/rev.)	0.15	0.25
D	Nose radius (mm)	0.4	0.8

2.3 Experimental procedure

In the present work, the machining process was studied under DOE whereby the factorial portion is a full factorial design (2^4) with all combinations of the factors at two levels. Turning is a popularly used machining process. As the CNC machines play a major role in modern machining industry to enhance product quality as well as productivity [22]. Cutting tests were carried out on 10 hp CNC lathe machine under dry conditions. The machining process on CNC lathe is programmed by speed, feed, and depth of cut. In total 16 work pieces (Φ25 mm x 70mm) are prepared. These work pieces cleaned prior to the experiments by removing 0.5mm thickness of the top surface from each work piece in order to eliminate any surface defects and wobbling. Two different nose radii of CVD coated inserts have been taken to study the effect of tool geometry. The surface rough nesses of machined surfaces are measured by a Mitutoyo SJ-201 surface roughness tester and measurements were repeated 3 times. The experimental design and results is given in Table-4.

Table-4. Experimental design and results.

Trial No.	Std order	Run order	Center Pt	Blocks	A	B	C	D	Ra µm
1	1	1	1	1	-1	-1	-1	-1	1.320
2	8	2	1	1	1	1	1	-1	1.583
3	12	3	1	1	1	1	-1	1	0.833
4	9	4	1	1	-1	-1	-1	1	0.730
5	4	5	1	1	1	1	-1	-1	1.300
6	16	6	1	1	1	1	1	1	1.683
7	14	7	1	1	1	-1	1	1	1.603
8	2	8	1	1	1	-1	-1	-1	1.310
9	5	9	1	1	-1	-1	1	-1	2.726
10	3	10	1	1	-1	1	-1	-1	1.350
11	7	11	1	1	-1	1	1	-1	2.736
12	15	12	1	1	-1	1	1	1	1.623
13	13	13	1	1	-1	-1	1	1	1.560
14	6	14	1	1	1	-1	1	-1	1.713
15	10	15	1	1	1	-1	-1	1	0.70
16	11	16	1	1	-1	1	-1	1	0.813

3. RESULTS AND DISCUSSIONS

The test data is given in Tables 4 to 7 and plots are developed with the help of a software package MINITAB 14. These results are analyzed using ANOVA for the purpose of identifying the significant factors, which affects the surface roughness.

Table-5. ANOVA test results.

Source of variation	Sum of squares (SS)	Degrees of Freedom (DF)	Mean squares (MS)	F ratio (MS/error)	Contribution (%)
A	0.28891	1	0.28891	4.974	5.640
B	0.00391	1	0.00391	0.0673	0.076
C	2.94981	1	2.94981	50.788	57.586
D	1.27126	1	1.27126	21.888	24.817
A*B	0.00076	1	0.00076	0.0130	0.015
A*C	0.25251	1	0.25251	4.347	4.929
A*D	0.33931	1	0.33931	5.8421	6.624
B*C	0.00276	1	0.00276	0.0475	0.054
B*D	0.01266	1	0.01266	0.2179	0.247
C*D	0.00051	1	0.00051	0.00878	0.009
Total	5.1224	10			
Error	0.2904	5	0.05808		

Table-6. Estimated effects and coefficients for surface roughness (Ra) (coded units).

	Effect	Coef	SE Coef	T	P
Term constant		1.4731	0.06289	23.42	0.000
A	-0.2688	-0.1344	0.06289	-2.14	0.086
B	0.0313	0.0156	0.06289	0.25	0.814
C	0.8588	0.4294	0.06289	6.83	0.001
D	-0.5638	-0.2819	0.06289	-4.48	0.007
A* B	-0.0138	-0.0069	0.06289	-0.11	0.917
A*C	-0.2512	-0.1256	0.06289	-2.00	0.102
A*D	0.2913	0.1456	0.06289	2.32	0.068
B* C	-0.0262	-0.0131	0.06289	-0.21	0.843
B* D	0.0563	0.0281	0.06289	0.45	0.673
C* D	-0.0113	-0.0056	0.06289	-0.09	0.932

S = 0.251548 R-Sq = 94.18% R-Sq (adj) = 82.55%

The results of ANOVA for the surface roughness are shown in Tables 5 and 6. This analysis is carried out for a significant level of α=0.05 (confidence level of 95%). The main effect of feed (the most significant parameter) (C), nosed radius (D) are significant. It is evident that 57.59% feed C is contributing on surface roughness than other cutting parameters. The nose radius is the next contributing factor. Based on Table-4, the optimal machining parameters for AISI 202 is obtained for the minimum value (R_a= 0.70 µm) of surface roughness. Based on the main effects graph (Figure-1), the optimal machining conditions achieved were; (a) cutting speed at level +1 (200 m/min) (b) feed at level-1 (0.15 mm/rev) (c) depth of cut at level -1 (0.25 mm) (d) nose radius at level +1 (0.8mm).

3.1 Interpretation of plots

The plots show the variation of individual response with the four parameters i.e. cutting speed, feed, depth of cut and nose radius separately. In the plots, the x-axis indicates the value of each parameter at two level and y-axis the response value. Horizontal line indicates the mean value of the response.

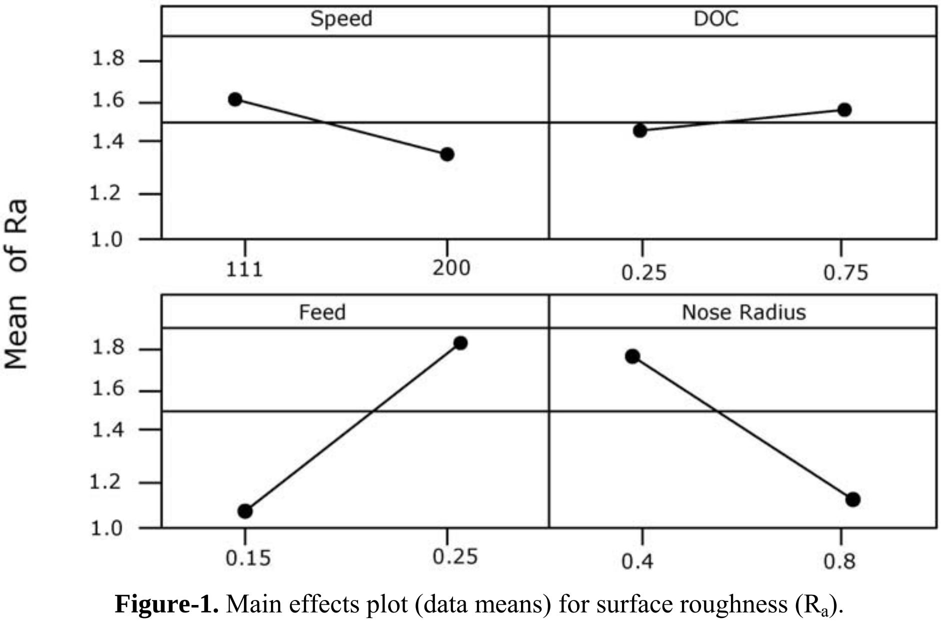

Figure-1. Main effects plot (data means) for surface roughness (R_a).

Figure-1 shows the main effect plot for work piece surface roughness for cutting speed, feed depth of cut and nose radius. The results show that with the increase in cutting speed and the nose radius there is a significant reduction in R_a value. The feed and R_a values are directly proportional to each other. The almost flat line shows that there is no effect due to depth of cut.

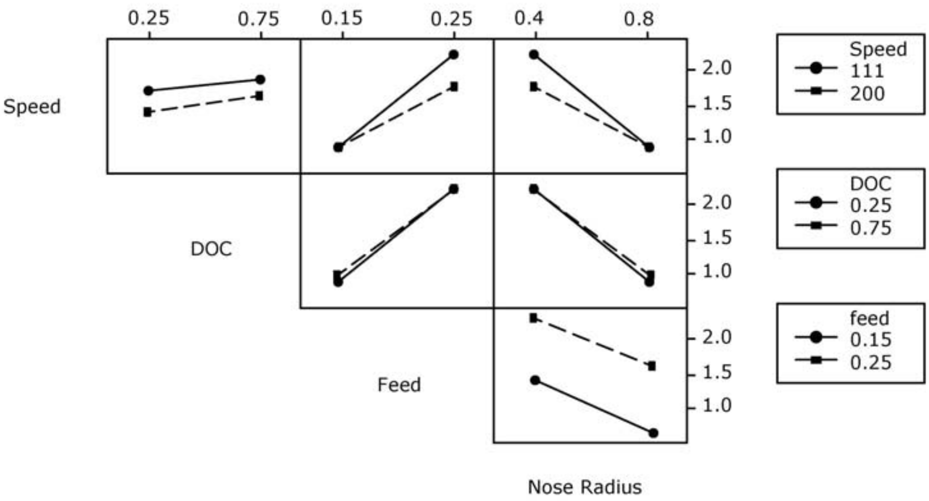

Figure-2. Interaction plot (data means) for surface roughness (R_a).

Results of interaction plots for R_a values (Figure-2) show that there is a less significant interaction effect in between cutting speed and feed. Similar effect is observed in between cutting speed and nose radius. Parallel lines show that there is no interaction effect between the parameters.

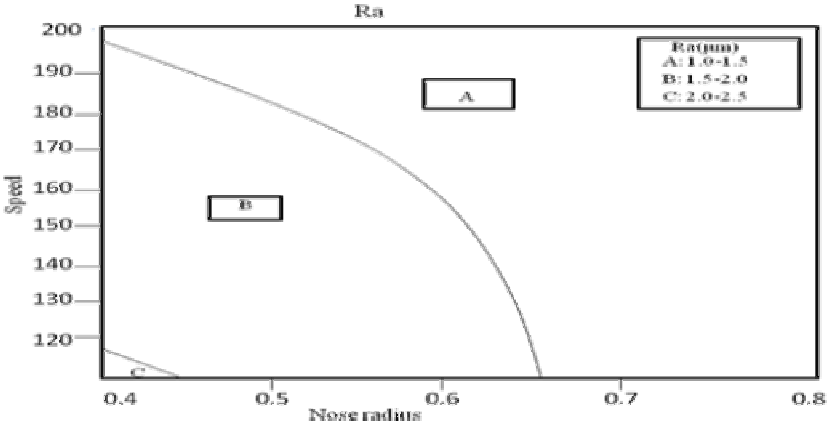

Figure-3. Contour plot of Ra Vs speed, nose radius.

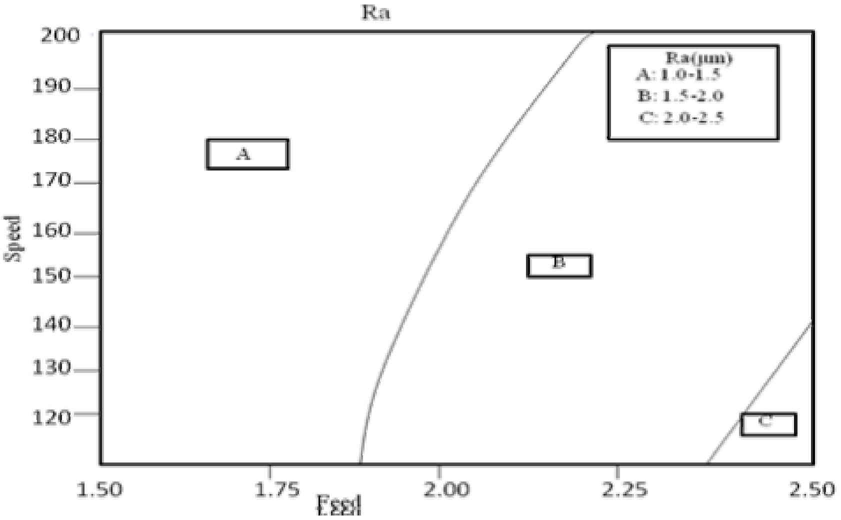

Figure-4. Contour plot of Ra Vs speed, feed.

Contour plots (Figures 3, 4) can help to predict the values of surface roughness at any zone of experimental domain.

Figure-5 shows that the two lines apart from the central line indicate upper and lower limits of confidence level 95%. It is observed that except one value, all the values are within the confidence interval of 95%. This tendency gives better results for future prediction, which has been confirmed by experiments.

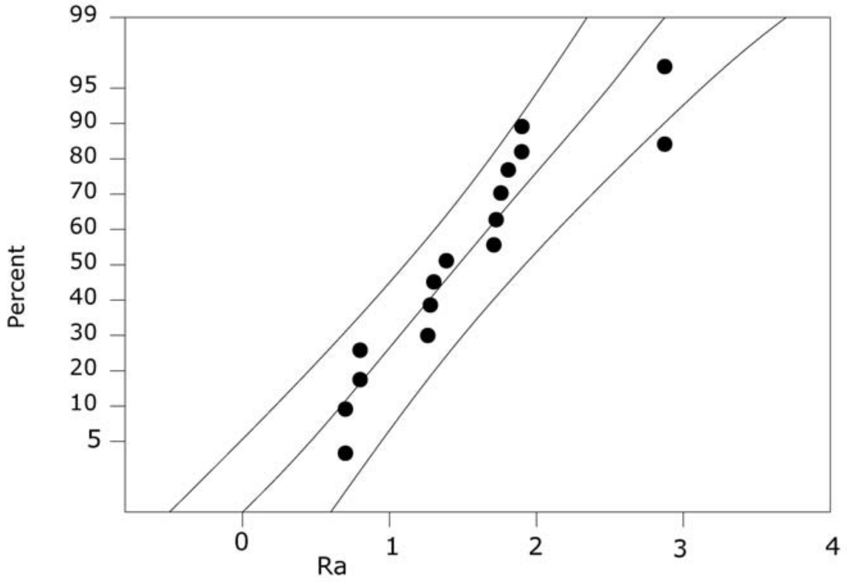

Figure-5. Normal probability plot for Ra.

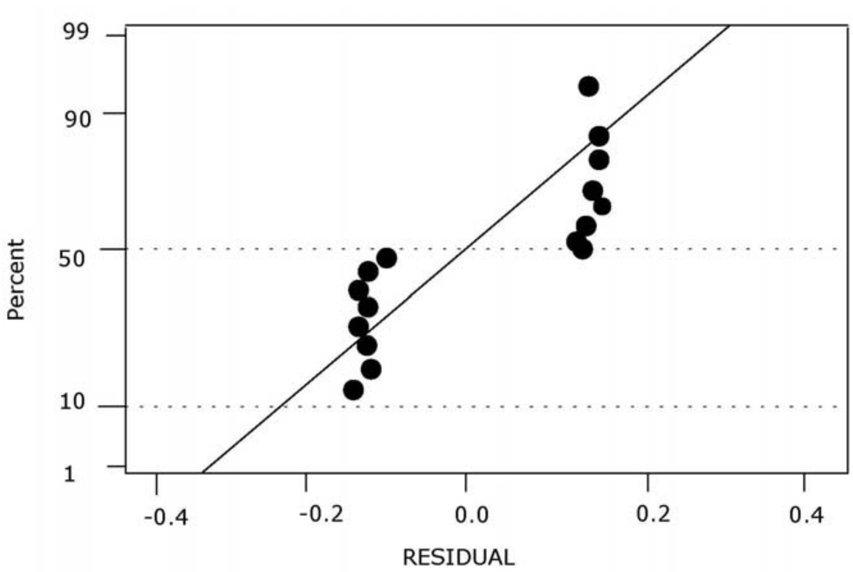

Figure-6. Normal probability plot.

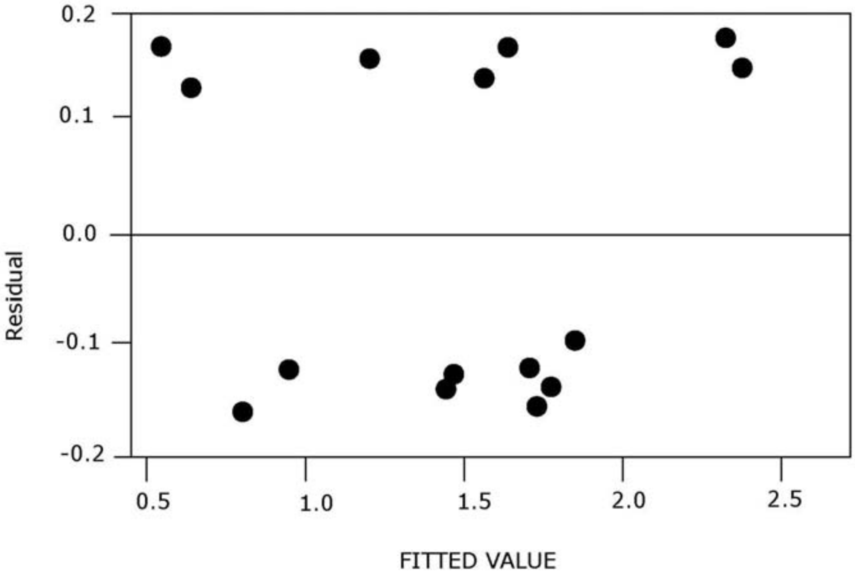

Figure-7. Residuals Vs the predicted values for residuals.

As shown in Figure-6 the residuals are spread along the straight line implying that the errors are distributed normally. It is clear from Figure-7 that it has no obvious pattern and unusual structure. This implies that the model proposed is adequate.

3.2 Correlation

The correlation among the factors i.e. cutting speed, feed, depth of cut and nose radius and performance measure (R_a) are obtained. The polynomial model obtained as follows:

R_a=1.4731+ 0.4294 * C - 0.2819 * D ---------Eq. (1)
(R^2 = 94.18%)

The above equation consists of only significant factors. The larger value of R^2 is always desirable. This confirms the suitability of models and the correctness of the calculated constants.

3.3 Optimality confirmation

Once the optimal has been selected, the next step is to predict and verify the improvement of surface roughness value of AISI202. The predicted optimal condition can be calculated by means of additive law.

$$R_{a(predicted)} = \overline{R_a} + \sum_{i=1}^{n}(R_0 - \overline{R_a}) \quad \text{-------------Eq. (2)}$$

The predicted optimum value of surface roughness for the optimum parameter levels is $R_{a\ (Predicted)}$ =0.60 µm. Where $\overline{R_a}$ is the grand mean surface roughness; R_O is the mean surface roughness at optimal level is the mean at optimal level and n is the number of main designing parameters that affect the machining process.

In order to validate, the experiment was conducted according to the optimal parameters levels (+1,-1,-1 and +1) and the corresponding values of performance measures were taken. From the results shown in Table-8, it is observed that the error obtained in polynomial model is smaller when compared with the additive model. A maximum error shown by the polynomial model is 11.76% and by the additive model is 18.33%. It is observed that the confirmation experiment result of Surface roughness value is improved by the optimal setting of parameters. Hence, it is proved that machining conditions are optimized.

Table-8. Results of the experimental confirmation for surface roughness (Ra) in µm.

Expt. values of surface roughness (Ra) **in µm**	**Predicted surface roughness values** (Ra) **in µm**			
	Polynomial model (by using Eq.1)	**Error**	**Additive model** (by using Eq.2)	**Error**
0.68	0.76	11.76%	0.60	13.33%
0.69	0.76	10.0%	0.60	15.0%
0.71	0.76	7.0%	0.60	18.33%

4. CONCLUSIONS

The following are conclusions drawn based on the experiment conducted in turning of AISI 202 steel with CVD coated cemented carbide cutting tool.

a) From the ANOVA Table, the feed and nose radius are significant factors.
b) 57.59% contributed by the feed on surface roughness and 24.82% contributed by the nose radius on surface roughness.
c) There is a slight inclination of significance in case of interaction between speed and nose radius to influence surface roughness when compared with other interactions.
d) It is observed that the predicted values and measured values are close to each other.
e) In order to obtain a good surface finish on AISI 202 steel, higher cutting speed, lower feed rate, lower depth of cut and higher nose radius are preferred.

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