International Journal of Scientific Research in Mechanical and Materials Engineering
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Optimization of Machining Parameters In A Turning Operation of Austenitic Stainless Steel To Minimize Surface Roughness And Tool Wear

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Article Info
Volume 6, Issue 2
Page Number : 74-91

Publication Issue :
March-April-2022

Article History
Accepted : 01 March 2022
Published : 20 April 2022

ABSTRACT

The current study used a TiAlN coated carbide insert tool to turn on austenitic stainless steel of grade AISI 202. The primary purpose of the following research was to use Response Surface Methodology to evaluate the impact of machining parameters such cutting speed, feed rate, and depth of cut on the surface roughness of the machined material and tool wear. The purpose was to find the best machining parameters for the specified tool and work materials in the experiment's chosen domain in order to reduce surface roughness and tool wear. The experiment was carried out in a 20-run experiment matrix with a full-factorial Central Composite Design (CCD) (CCD). A Talysurf was used to quantify surface roughness, and a Toolmaker's microscope was used to measure tool wear. MINITAB ® 17 was used to compile the data for analysis. To develop and analyse the link between the machining parameters and the response variables (surface roughness and tool wear), the Response Surface Methodology was employed (RSM). Analysis of Variance (ANOVA) was used to analyse the importance of these parameters on the response variables and to develop a regression equation for the response variables with the machining parameters as independent variables using a quadratic model. We obtained and evaluated ANOVA main effects and interaction graphs, as well as contour and 3-D surface plots. The quadratic models were found to be significant with p-values of 0.033 and 0.049. The findings revealed that feed had the greatest impact on surface roughness, followed by cutting speed and depth of cut, whereas depth of cut was shown to be the only significant factor affecting tool wear. The top three optimal settings for carrying out the machining were offered by Response Surface Optimizer, which are listed in the results section.

Keywords : TiAlN, CCD, Talysurf, ANOVA

I. INTRODUCTION

The turning operation is a fundamental metal machining process that is frequently employed in metal cutting industries [1]. The selection of machining parameters for a turning operation is a critical step in achieving good performance [2]. We define high performance as good machinability, better surface finish, lower tool wear, higher material removal rate, faster rate of production, and so on.

A product's surface finish is typically quantified in terms of a metric known as surface roughness. It is regarded as a product quality indicator [3]. Enhanced surface polish can result in improved strength qualities such as corrosion resistance, temperature resistance, and longer fatigue life of the machined surface [4,5]. Surface finish, in addition to strength attributes, can affect the functional behaviour of machined components, such as friction, light reflective properties, heat transmission, ability to distribute and hold a lubricant, and so on [6,7]. Surface finish has an impact on production costs as well [3]. For the aforementioned reasons, minimising surface roughness is critical, which can be accomplished by optimising some of the cutting settings.

Tool wear is a natural occurrence in all classic cutting operations. Researchers attempt to eliminate or reduce tool wear since it affects both product quality and production costs. Extensive investigations on tool wear characteristics must be undertaken in order to improve tool life [8]. Machining parameters such as cutting speed, feed, depth of cut, and so on, as well as tool material and its properties, work material and its properties, and tool geometry, are all factors that influence tool wear and surface roughness. Minor adjustments in the aforementioned criteria can have a considerable impact on product quality and tool life [3].

Optimization is required to attain the desired results. Optimization is the science of achieving the best possible results while dealing with a variety of resource restrictions. In today's world, businesses and researchers must optimise to satisfy the growing need for increased product quality while also lowering manufacturing costs and increasing production rates [9]. Statistical design of experiments is often utilised in optimization processes. The process of organising experiments so that appropriate data can be analysed statistically, resulting in reliable and objective findings [10] is referred to as statistical design of experiments. Design methods such as Response Surface Methodology (RSM), Taguchi's method, factorial designs, and so on are finding widespread use nowadays, replacing the previous one factor at a time experimental approach, which was both more expensive and time-consuming [11].

Neseli et al. [4] employed the RSM method with nose radius, approach angle, and rake angle as input variables and discovered that the nose radius had the greatest influence on surface roughness.

Nanavati and Makadia [3] used feed, cutting speed, and tool nose radius as predictors in their RSM technique and discovered that feed was the most important component in determining surface roughness, followed by tool nose radius. The Taguchi technique was used by Yang and Tarng [2] to discover the optimal cutting parameters. According to a study by Bouacha [5,] the feed rate was the most important factor in affecting the smoothness of a product's surface, followed by the cutting speed. The depth of cut, according to Halim [14], has the biggest impact on tool wear, while other factors appear to be negligible. Cutting speed, feed, and depth of cut are used as machining parameters in this study, with the purpose of optimising these parameters to obtain the lowest surface roughness and tool wear possible.

II. OBJECTIVES OF PRESENT WORK

Tool wear is an unavoidable part of every machining operation. Tool life and product quality are both affected by wear. As a result, modifications must be made in order to extend tool life.

Surface finish is also an important aspect of a machined product.

a) To see how machining variables like speed, feed, and depth of cut affect the tool wear of a clamped insert-type tool.

b) To look into how machining variables like speed, feed, and depth of cut affect the surface roughness of machined material.

c) Using RSM, calculate the optimum machining parameter settings for the selected tool/work combination in order to reduce tool wear and surface roughness.

d) Create an empirical model for Surface Roughness and Tool Wear for the selected tool/work combination within the parameters specified.

III. RELATED LITERATURE REVIEW

Alagarsamy, S. V. et al., (2020) Using the Taguchi technique, the machining parameters of brass C26130 alloy are optimised during the CNC end milling process. The testing results reveal that the combination of 750 rpm spindle speed, 20 mm/rev feed rate, and 1 mm depth of cut is the best for minimum surface roughness (SR), and the combination of 750 rpm spindle speed, 60 mm/rev feed rate, and 0.75 mm depth of cut is the best for least tool wear (TW). The ANOVA findings suggested that the spindle speed and feed rate were the most influential parameters on SR and TW.

Bhushan, Rajesh Kumar (2020) Green production necessitates minimising waste. The production of fewer chips has a less negative impact on the environment. The nose radius plays a significant influence in chip development. The right nose radius and machining settings will limit the amount of chip and so safeguard the environment. Abrasion was discovered to be the primary cause of tungsten carbide insert wear while turning AA7075/15 wt. percent SiC (20 - 40 m) composites. This study is unique in that no one has previously explored the impact of nose radius and machining parameters on surface roughness, tool wear, and tool life during turning of AA7075/15 wt. percent SiC composites. The findings of this study will be beneficial to the automobile, aeroplane, space, and ship industries.

Yildirim et al., (2020) Although nickel-based aerospace superalloys such as alloy 625 have exceptional qualities such as high tensile and fatigue strength, corrosion resistance, and good weldability, among others, its machinability is a difficult issue that can be overcome by using alternate cooling/lubrication strategies. When turning alloy 625, a medium cutting speed (75m/min) is recommended for the lowest roughness value and lowest peak-to-valley height. Furthermore, as compared to cryogenic machining, MQL and CryoMQL reduce tool wear by 50.67% and 79.60%, respectively. An intriguing finding is that MQL reduces cutting tool wear more effectively than cryogenic machining.

IV. MATERIALS AND METHODS

The finished experiment piece was made of AISI 202 grade Austenitic stainless steel. Austenitic stainless steels are classified into two series: 300-series and 200-series. The 300 series steels are the most widely used around the world, although the 200 series has grown increasingly popular in the Asian subcontinent as an alternative to the 300 series to offset nickel price increases [27].

Grade 202 steel is available in plates, sheets, and coils and is widely used in restaurant equipment, culinary utensils, sinks, automotive trims, architectural applications such as doors and windows, railway trains, trailers, and horse clamps, among other things. [28].

Table 1 : Chemical composition (wt %) of AISI 202 Steel

Element	**Wt %**
Iron, Fe	68
Chromium, Cr	17-19
Nickel, Ni	4-6
Manganese, Mn	7.5-10
Silicon, Si	1
Nitrogen, N	0.25
Carbon	0.15
Phosphorous, P	0.06
Sulphur, S	0.03

Table 2 : Mechanical Properties of AISI 202 Steel

Property	**Value**
Tensile Strength	515 MPa
Yield Strength	275 Mpa
Elastic Modulus	207 Gpa
Poisson‟s Ratio	0.27-0.30
Elongation at break	40%

INSERT MATERIAL

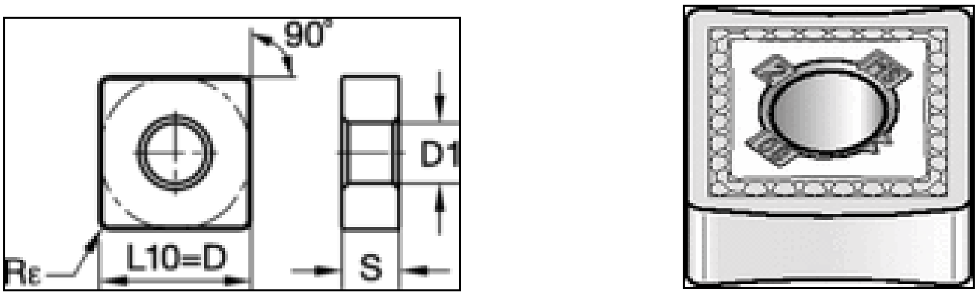
The tool insert selected was a coated carbide tool (Kennametal brand), the specs of which are provided below. Coated carbide tools outperform uncoated carbide tools. [11].

Table 3 : Specification of Cutting Tool

<table>
<tr><th rowspan="3">ISO
Catalog Number</th><th rowspan="3">ANSI
Catalog Number</th><th rowspan="3">Grade</th><th colspan="10">Dimensions</th></tr>
<tr><th colspan="2">D</th><th colspan="2">L10</th><th colspan="2">S</th><th colspan="2">R ε</th><th colspan="2">D1</th></tr>
<tr><th>mm</th><th>in</th><th>mm</th><th>in</th><th>mm</th><th>in</th><th>mm</th><th>in</th><th>mm</th><th>in</th></tr>
</table>

SNMG 120408	SNMG 432MS	KCU25	12.70	0.5	12.70	0.5	4.76	0.1875	5.16	0.203

The chosen insert (Fig 12 from [29]) was a square type negative insert, which meant it was rotatable and reversible, allowing for a total of 8 cutting edges. KCU25 employs PVD coating technology, which includes unique surface treatments that improve machining performance in high-temperature materials [29]. The insert's coating is TiAlN. (Titanium Aluminium Nitride).



(a) (b)

Fig 1 : Selected cutting tool insert [29]

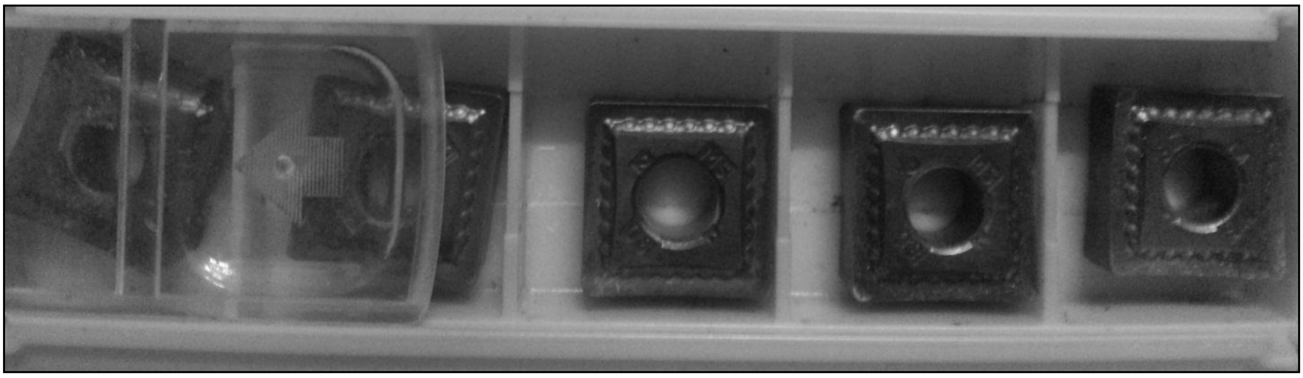


Fig 2: Set of cutting inserts used in the experimentation

EXPERIMENTAL SETUP AND INITIAL PREPARATION

The machining was done on a centre lathe. The insert was installed on the tool post after being clamped in a holder. The task was held tightly in place by the lathe's chuck. The job was held at the opposite end by the tail stock while the centre drilling was completed, and a skin pass was performed. As a result, the setup was completea, and the runs could begin from here.

Fig 3: Experimental Setup

Fig 4: Mounting of tool and workpiece

CUTTING CONDITION

The experimentation was carried out in a dry cutting setting. A dry cutting process is one in which no coolant is used during the machining process. The use of dry cutting reduced the cost of cutting fluid. Cutting fluids are caustic and harmful to the environment. Dry cutting saves money on machining and is better for the environment. Furthermore, inserts operate better at higher cutting temperatures obtained during dry cutting [14].

MEASUREMENT OF SURFACE ROUGHNESS

Surface roughness was properly measured using Talysurf (Taylor Hobson, Surtronic 3+, UK), a portable stylus-type profilometer. Measurements were taken at various places, and the average for each run was reported.

Fig 5: Setup of Talysurf for measurement of Surface Roughness

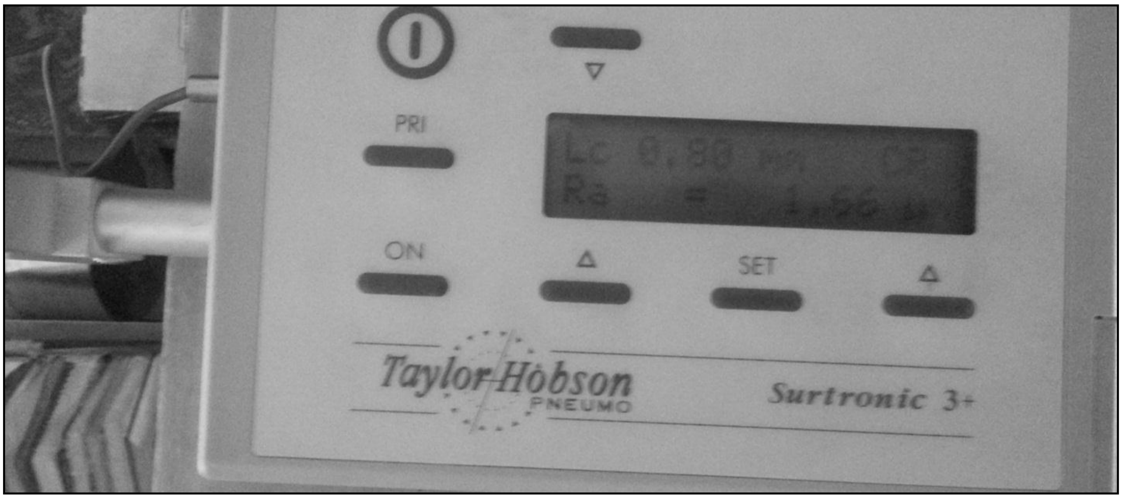


Fig 6: Reading shown in Talysurf

MEASUREMENT OF TOOL WEAR

For each run, a new cutting edge was used. The tool wear that resulted was measured using a Toolmaker's Microscope (Fig 18) with a digital read-out device (Fig 20). Figure 19 shows depicts a view of the tool insert through the eyepiece.

Table 4: Specification of Toolmaker's Microscope

1.1	Nr	14832
DDR	Made in the CDR Achsenhohe 42.52 mm	
1554		

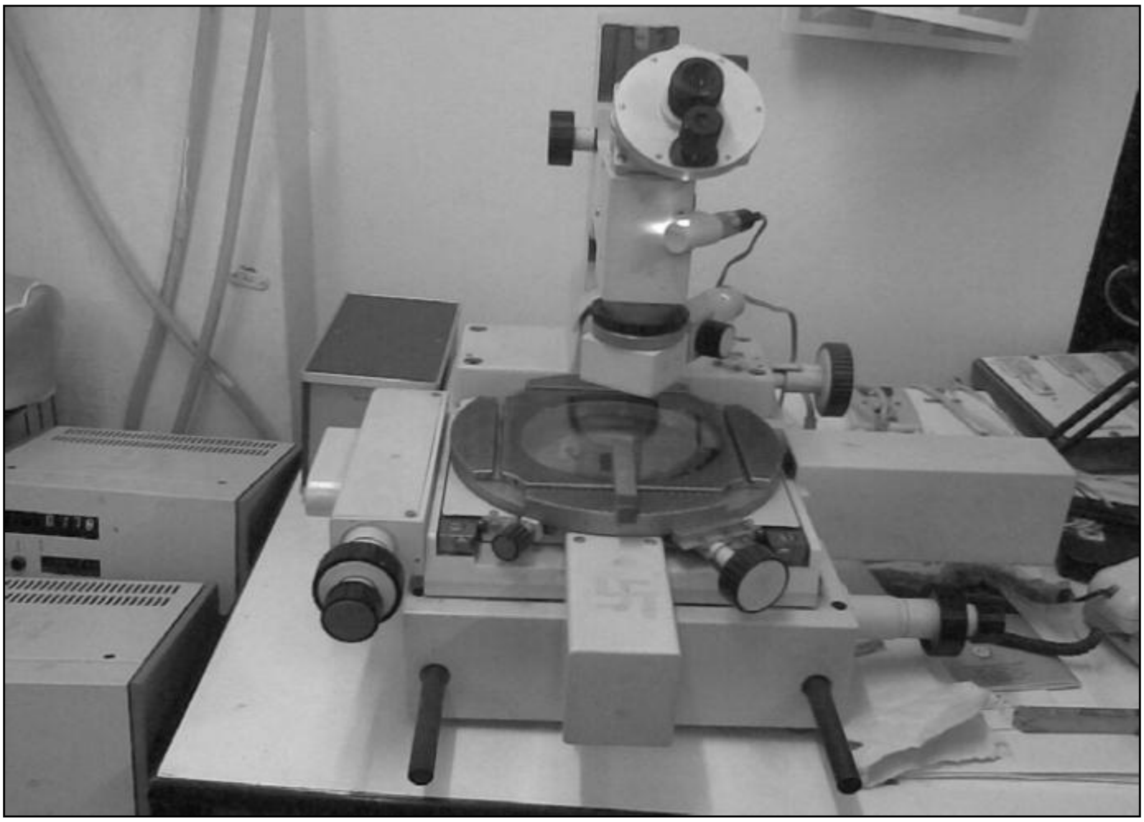


Fig 7: Toolmakers' Microscope

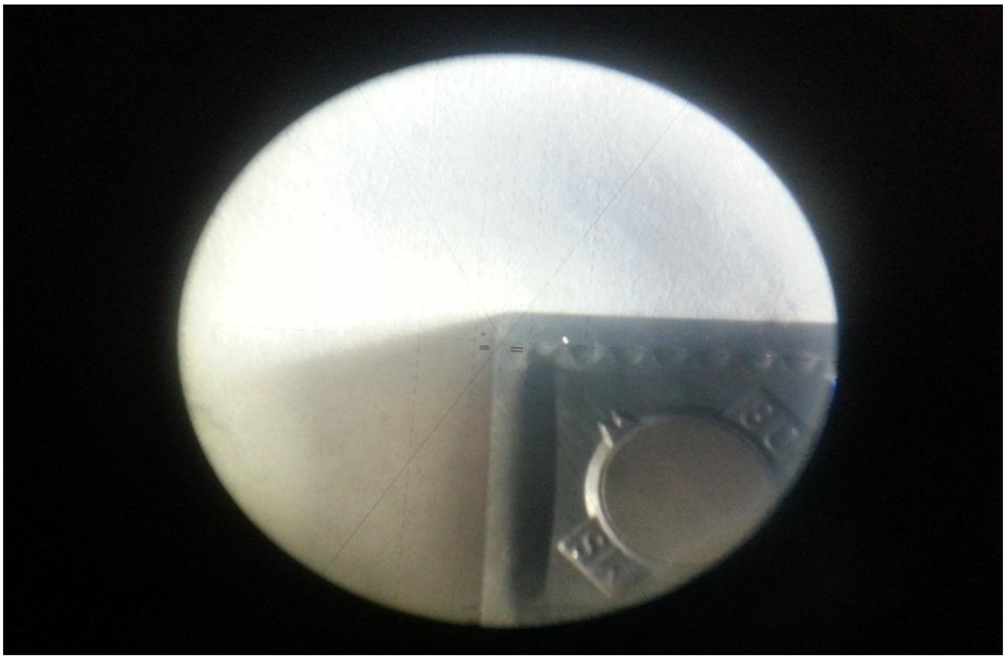


Fig 8: View of the insert through the eyepiece

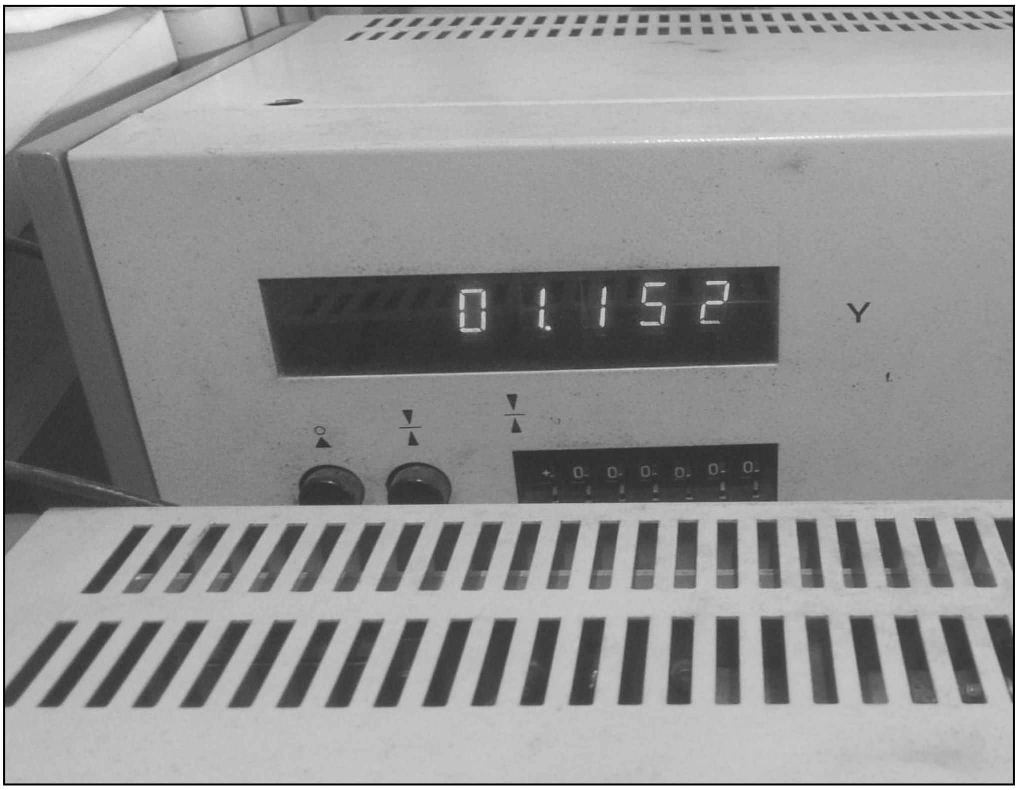


Fig 9: Digitized reading of tool wear

EXPERIMENTAL RESULTS

The results obtained from the experimental work are summarized in the Table 7.

Table 7: Results Obtained

StdOrder	RunOrder	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Ra (μm)	Flank wear (mm)
1	4	66	0.05	0.4	0.947	0.443
2	1	112	0.15	0.4	1.513	0.768
3	3	112	0.05	0.8	1.353	0.932
4	2	66	0.15	0.8	1.7	1.17
5	15	89	0.1	0.6	0.86	1.629
6	16	89	0.1	0.6	0.887	1.209
7	7	112	0.05	0.4	0.88	0.487
8	6	66	0.15	0.4	1.947	0.57
9	8	66	0.05	0.8	1.893	1.104
10	5	112	0.15	0.8	1.673	1.151
11	17	89	0.1	0.6	1.053	1.844
12	18	89	0.1	0.6	1	1.604
13	10	66	0.1	0.6	1.16	0.928
14	9	112	0.1	0.6	0.96	1.001
15	13	89	0.05	0.6	2.16	0.948
16	11	89	0.15	0.6	2.013	0.859
17	12	89	0.1	0.4	1.413	0.788
18	14	89	0.1	0.8	1.007	1.116
19	19	89	0.1	0.6	0.967	1.807
20	20	89	0.1	0.6	0.96	1.793

ANALYSIS OF RESULTS AND PLOTS

The results obtained from the experiment were fed into MINITAB ® 17 for further analysis.

ANOVA

The significance and influence of the cutting parameters on the response variables, Ra and Tool wear, were investigated using the analysis of variance (ANOVA) method (shown in Tables 8 and 9).

Table 8: ANOVA for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2.7542	0.30602	3.47	0.033
Linear	3	0.50671	0.1689	1.92	0.191
Cutting Speed	1	0.16078	0.16078	1.82	0.207
Feed	1	0.26018	0.26018	2.95	0.117
Depth of Cut	1	0.08575	0.08575	0.97	0.347
Square	3	1.96078	0.65359	7.41	0.007
Cutting Speed*Cutting Speed	1	0.16281	0.16281	1.85	0.204
Feed*Feed	1	1.68678	1.68678	19.13	0.001
Depth of Cut*Depth of Cut	1	0.02395	0.02395	0.27	0.614
2-Way Interaction	3	0.28671	0.09557	1.08	0.4
Cutting Speed*Feed	1	0.00266	0.00266	0.03	0.865
Cutting Speed*Depth of Cut	1	0.00054	0.00054	0.01	0.939
Feed*Depth of Cut	1	0.2835	0.2835	3.21	0.103
Error	10	0.88184	0.08818		
Lack-of-Fit	5	0.8564	0.17128	33.66	0.11
Pure Error	5	0.02545	0.00509		
Total	19	3.63604			

Table 7 shows that the model's P-Value is 0.033, which is less than the significance level of 0.05. As a result, the model is significant. With a P-value of 0.11, the lack-of-fit is insignificant, which is acceptable. Feed is discovered to be the most influential parameter influencing surface roughness, having the lowest P-value of any of the three parameters.

Table 9: ANOVA for Tool Wear

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2.46551	0.273945	2.57	0.049
Linear	3	0.62221	0.207403	1.95	0.186
Cutting Speed	1	0.00154	0.001538	0.01	0.907
Feed	1	0.03648	0.036782	0.34	0.571
Depth of Cut	1	0.58419	0.584189	5.48	0.041
Square	3	1.80619	0.602063	5.65	0.016
Cutting Speed*Cutting Speed	1	0.12033	0.120332	1.13	0.313
Feed*Feed	1	0.20075	0.200745	1.88	0.2
Depth of Cut*Depth of Cut	1	0.13514	0.135143	1.27	0.286
2-Way Interaction	3	0.03711	0.012369	0.12	0.949
Cutting Speed*Feed	1	0.01178	0.011781	0.11	0.746
Cutting Speed*Depth of Cut	1	0.02344	0.023436	0.22	0.649
Feed*Depth of Cut	1	0.00189	0.001891	0.02	0.897
Error	10	1.06518	0.106518		
Lack-of-Fit	5	0.8564	0.157088	2.81	0.141
Pure Error	5	0.27974	0.055948		
Total	19	3.53068			

According to Table 8, the P-Value for the model is 0.049, which is less than the significance value of 0.05. As a result, the model is significant. With a P-value of 0.141, the lack-of-fit is insignificant, which is ideal. The depth of cut is discovered to be the most influential parameter influencing stool wear, with the lowest P-value (0.041, significant) of all three parameters.

Figures 21–24 show the main effects and interaction effects plots for surface roughness and tool wear.

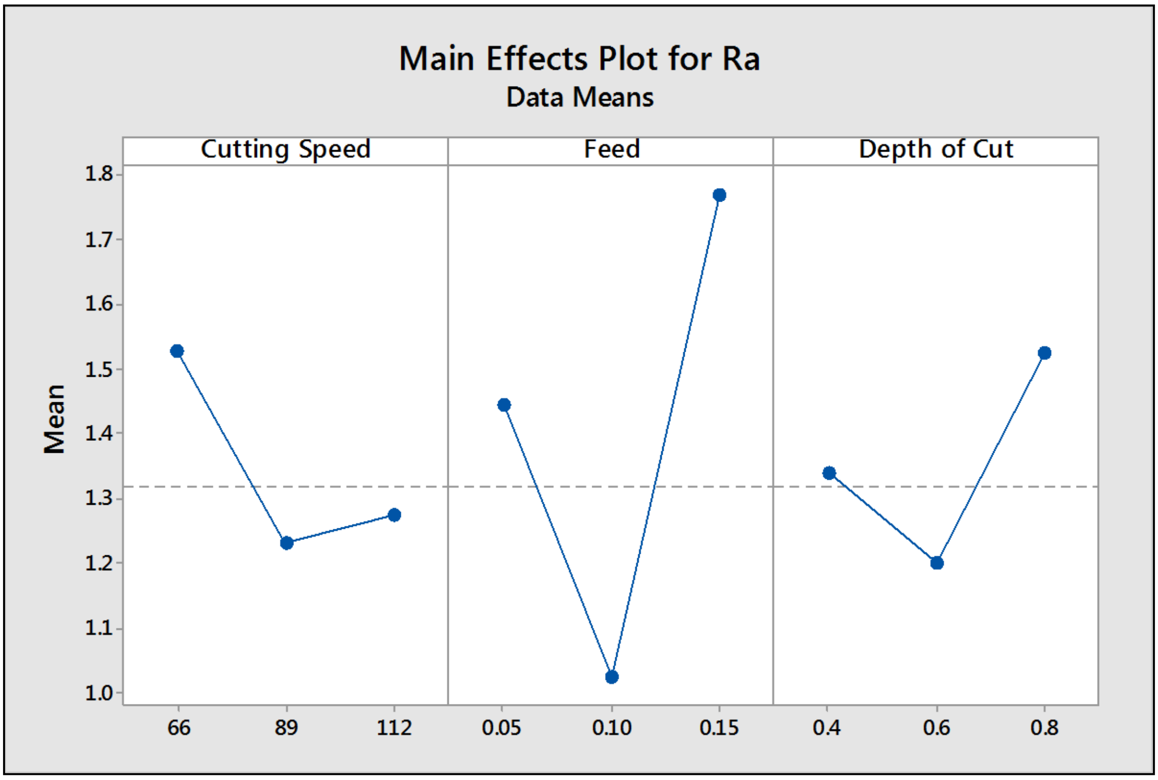


Fig 10: Main effects plot for Ra

The major effects plot for Ra (Fig 10) demonstrates that when cutting velocity increases, surface roughness reduces sharply at first. After a certain point, it gradually increases with increasing cutting velocity. The same thing happens with feed, however the increase after that point is rather steep. Ra also decreases as the depth of cut increases to that level, after which it begins to rise steeply as the depth of cut increases further.

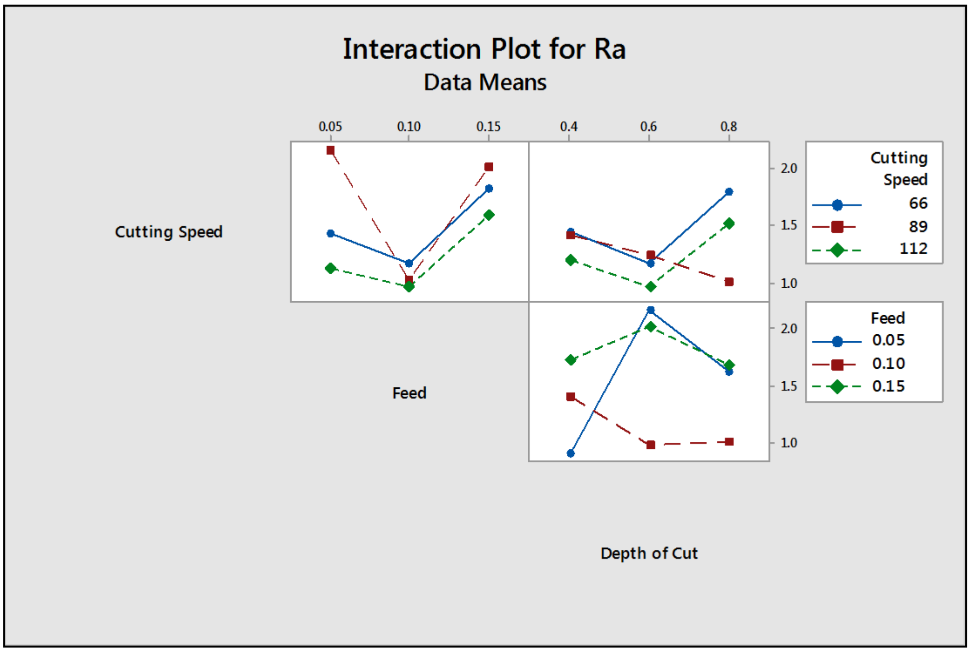


Fig 11: Interaction plot for Ra

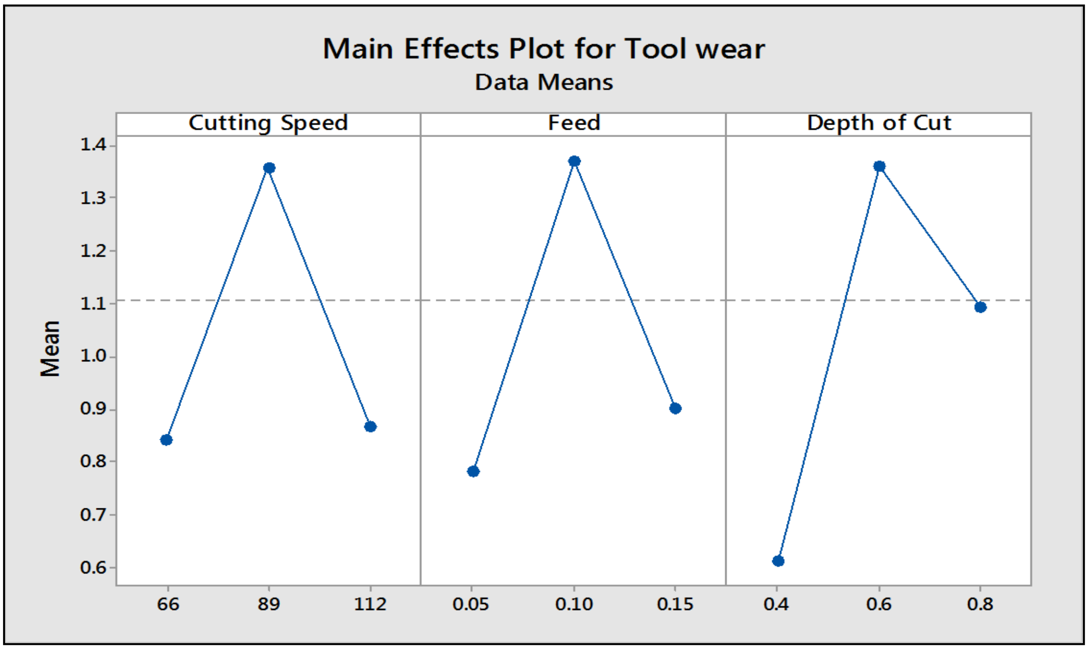


Fig 12: Main effects plot for Tool wear

The major effects plot for tool wear (Fig12) shows that increasing any of the three factors up to a particular level causes a significant increase in tool wear while keeping the other parameters constant. Wear decreases as the cutting speed, feed rate, or depth of cut increase while the other parameters remain constant.

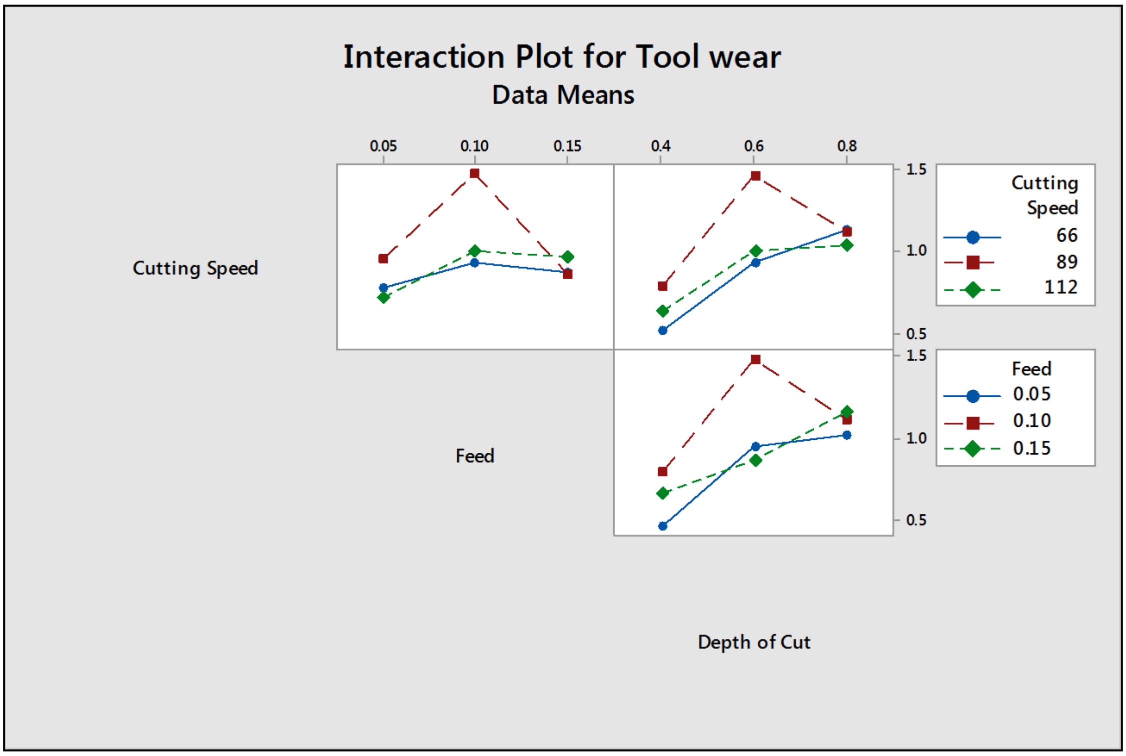


Fig 13: Interaction plot for Tool Wear

The regression coefficients obtained from MINITAB ® 17 are laid out in Tables 10 and 11.

Table 10: Estimated Coded Regression Coefficients for Surface Roughness

Term	Effect	Coef	SE Coef	T-Value	P-Value
Constant		1.094	0.102	10.72	0
Cutting Speed	-0.2536	-0.1268	0.0939	-1.35	0.207
Feed	0.3226	0.1613	0.0939	1.72	0.117
Depth of Cut	0.1852	0.0926	0.0939	0.99	0.347
Cutting Speed*Cutting Speed	-0.487	-0.243	0.179	-1.36	0.204
Feed*Feed	1.566	0.783	0.179	4.37	0.001
Depth of Cut*Depth of Cut	-0.187	-0.093	0.179	-0.52	0.614
Cutting Speed*Feed	0.037	0.018	0.105	0.17	0.865
Cutting Speed*Depth of Cut	-0.017	-0.008	0.105	-0.08	0.939
Feed*Depth of Cut	-0.376	-0.188	0.105	-1.79	0.103

Regression Equation in Un-coded Units:

$$Ra = -1.45 + 0.0758Vc - 49.5f + 5.30d - 0.00046Vc^2 + 313.3f^2 - 2.33d^2 + 0.0519Vc*f - 0.0018Vc*d - 18.8f*d \quad (10)$$

Table 11: Estimated Coded Regression Coefficients for Tool Wear

Term	Effect	Coef	SE Coef	T-Value	P-Value
Constant		1.458	0.112	13	0
Cutting Speed	0.025	0.012	0.103	0.12	0.907
Feed	0.121	0.06	0.103	0.59	0.571
Depth of Cut	0.483	0.242	0.103	2.34	0.041
Cutting Speed*Cutting Speed	-0.418	-0.209	0.197	-1.06	0.313
Feed*Feed	-0.54	-0.27	0.197	-1.37	0.2
Depth of Cut*Depth of Cut	-0.443	-0.222	0.197	-1.13	0.286
Cutting Speed*Feed	0.077	0.038	0.115	0.33	0.746
Cutting Speed*Depth of Cut	-0.108	-0.054	0.115	-0.47	0.649
Feed*Depth of Cut	-0.031	-0.015	0.115	-0.13	0.897

Regression Equation in Un-coded Units:

$$\text{Tool Wear} = -6.07 + 0.0746Vc + 20.8f + 9.06 - 0.000395Vc^2 - 108.1f^2 - 5.54d^2 + 0.033Vc*f - 0.0118Vc*d - 1.5f*d \quad (11)$$

RESIDUAL PLOTS

Fig 14 and Fig 15 display the residual plots for the surface roughness and the tool wear.

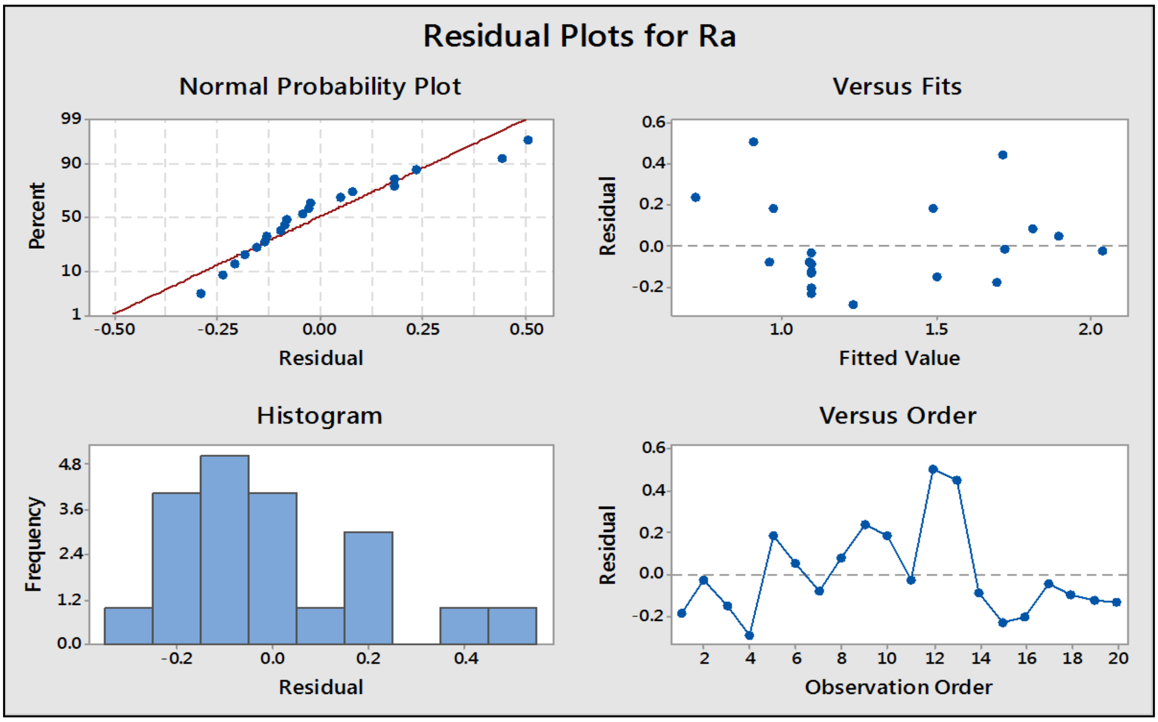


Fig 14 : Residual Plots for Ra

The model is adequate, as evidenced by the points in the normal probability plot falling on a straight line. It denotes that the errors are dispersed normally. Furthermore, the plot of the residuals vs the projected response lacks structure, including no discernible pattern.

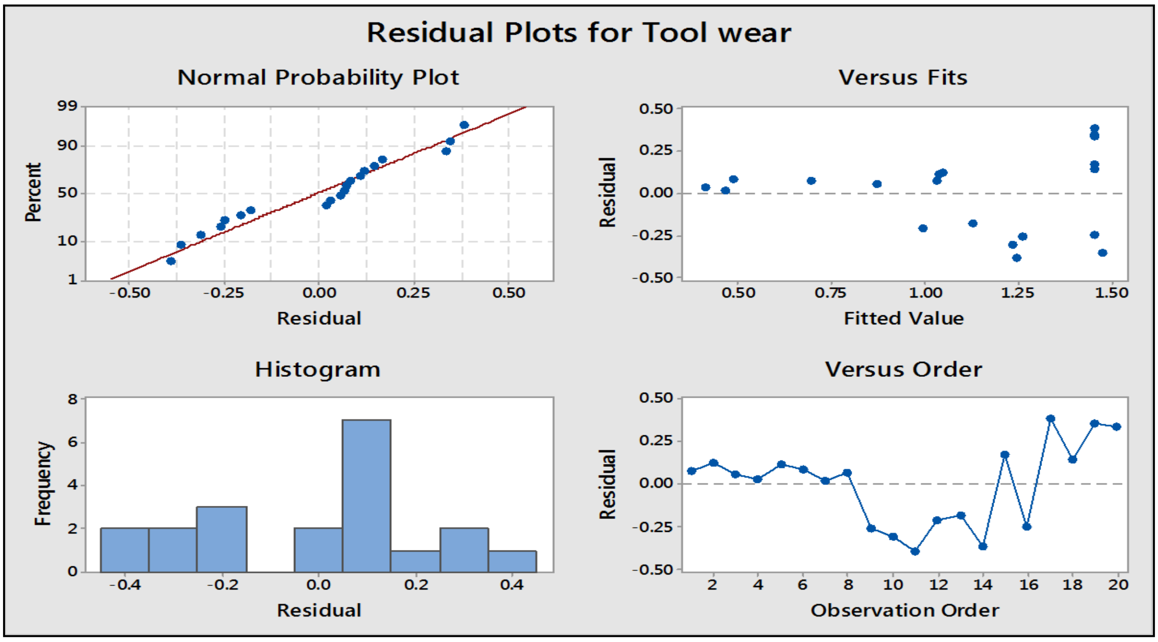


Fig 15 : Residual plots for Tool Wear

Again, the model is adequate, as seen by the points in the normal probability plot falling on a straight line. It indicates that the errors are normally distributed, as they should be for a well-fit model. The normal distribution on the histogram is likewise approximately bell-shaped.

Furthermore, the plot of residuals versus expected tool wear is structureless, with no discernible pattern.

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V. CONCLUSION

RSM was effectively used to optimise surface roughness and tool wear for the selected tool-work combination and domain of input machining parameters. ANOVA analysis was performed, and it was discovered that feed is the most significant factor impacting surface roughness, closely followed by cutting speed and depth of cut, whereas the depth of cut is the sole significant factor affecting tool wear. The best running conditions were discovered to be V c (112 m/min), f (0.0540404 mm/rev), and d. (0.4 mm). Empirical models for surface roughness and tool wear have been developed, from which predictions for output responses for relevant applications may be made.

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Cite this article as :

Vijay Krishna Chaturvedi, Nitin Shukla, "Optimization of Machining Parameters In A Turning Operation of Austenitic Stainless Steel To Minimize Surface Roughness And Tool Wear",International Journal of Scientific Research in Mechanical and Materials Engineering (IJSRMME), ISSN : 2457-0435, Volume 6 Issue 2, pp. 74-91, March-April 2022.
URL : https://ijsrmme.com/IJSRMME226210