Optimization of Machining Parameters in A Turning Operation of AISI 202 Austenitic Stainless Steel to Minimize Tool Wears

Chandan Kumar[1], Mohammad Nehal Akhtar[2], Priti Singh[3]
[1, 2, 3] Department of Mechanical Engineering
[1, 2, 3] AIET Lucknow, UP, India

Abstract- *The present work concerned an experimental study of turning on Austenitic Stainless steel of grade AISI 202 by a TiAlN coated carbide insert tool. The primary objective of the ensuing study was to use the Response Surface Methodology in order to determine the effect of machining parameters viz. cutting speed, feed, and depth of cut, on the tool wear of the machined material. The objective was to find the optimum machining parameters so as to minimize the tool wear for the selected tool and work materials in the chosen domain of the experiment. The experiment was conducted in an experiment matrix of 20 runs designed using a full-factorial Central Composite Design (CCD). Tool wears are measured with the help of a Toolmaker's microscope. The data was compiled into MINITAB ® 17 for analysis. The relationship between the machining parameters and the response variable (tool wear) were modeled and analysed using the Response Surface Methodology (RSM). Analysis of Variance (ANOVA) was used to investigate the significance of these parameters on the response variables, and to determine a regression equation for the response variables with the machining parameters as the independent variables, with the help of a quadratic model. Main effects and interaction plots from the ANOVA were obtained and studied along with contour and 3-D surface plots.*

Keywords- Turning, RSM, Cutting Speed, Depth of Cut, Tool Wear, CCD, ANOVA, etc.

I. INTRODUCTION

The work piece used for the concluded experiment was AISI 202 grade Austenitic stainless steel. There are two series of Austenitic stainless steels – 300-series and 200-series. 300 series steels find most wide use around the world but 200 series have become very popular in the Asian subcontinent as an alternative to the 300 series to counter the increase in prices of Nickel.

Grade 202 steel can be made into plates, sheets and coils and finds extensive use in restaurant equipment, cooking utensils, sinks, automotive trims, architectural applications such as doors and windows, railways cars, trailers, horse clamps etc.

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. In a turning operation, a high-precision single point cutting tool is rigidly held in a tool post and is fed past a rotating work piece in a direction parallel to the axis of rotation of the work piece, at a constant rate, and unwanted material is removed in the form of chips giving rise to a cylindrical or more complex profile. This operation is carried out in a Lathe Machine either manually under an operator's supervision, or by a controlling computer program.

Tool wear is an inherent occurrence in every conventional machining process. Bin Halim said that the tool wear is analogous to the gradual wear of the tip of a pencil [1]. It is the gradual failure of cutting tools due to regular operation.

The tool wear rate is dependent on the tool material itself, the tool shape and geometry, work piece material etc. The foremost important factors affecting the tool wear which can be easily controlled are process parameters. A key factor in the rate of tool wear of materials is the temperature achieved during machining.

The general idea is that energy expended in cutting is converted into heat and that a large fraction of it is taken away in the chip. This results in about 20% of the heat generated going into the cutting tool. The following types of tool wear modes can be observed [2]:

a) Flank
b) Notch
c) Crater
d) Edge rounding
e) Edge chipping
f) Edge cracking
g) Catastrophic failure

Flank wear and Crater wear are the two major types of wear which are present almost instantaneously even for low machining times. This study will be focusing on these two types only as our machining time was chosen to be 1 min [3].

Flank wear is the wear that occurs on the flank surface or flank faces of the cutting tool. This occurs due to direct mechanical abrasion and friction between the flank surface and the work piece during the operation. The width of the wear land is a straightforward measure of the flank wear [4]. The width is denoted as VB. The tool life is conventionally considered to be over when the average flank wear land VB reaches 300 µm or the maximum flank wear land VB max becomes 600 µm. Choudhury and Srinivas [1], found that cutting speed and diffusion coefficient index have the most notable effect on the flank wear, followed by feed and depth of cut.

Crater wear is the wear that takes place on the rake face or the top face of the cutting tool. It occurs parallel to the principal cutting edge. This type of erosion occurs due to the rubbing of the chip on the rake face during machining [4]. According to Kalpakjian and Schmid, the most notable factors that affect the crater wear phenomena are temperature occurring at the chip-tool interference and the chemical affinity between the tool and work materials at the elevated temperatures encountered during machining. Factors affecting flank wear also influence crater wear . B.V. Manoj Kumar, J. Ram Kumar and Bikramjit Basu, found out during the dry machining of boiler steel using TiCN-Ni-WC cermet inserts that crater wear increases significantly with cutting speed and feed.

1. MACHINING PARAMETERS

The turning operation is governed by geometry factors and machining factors. This study consists of the three primary adjustable machining parameters in a basic turning operation viz. speed, feed and depth of cut. Fig 2 shows these three parameters. Material removal is obtained by the combination of these three parameters.

Cutting speed may be defined as the rate at which the uncut surface of the work piece passes the cutting tool [4]. It is often referred to as surface speed and is ordinarily expressed in m/min, though ft. /min is also used as an acceptable unit [4, 5]. Cutting speed can be obtained from the spindle speed. The spindle speed is the speed at which the spindle, and hence, the work piece, rotates. It is given in terms of number of revolutions of the work piece per minute i.e. rpm.

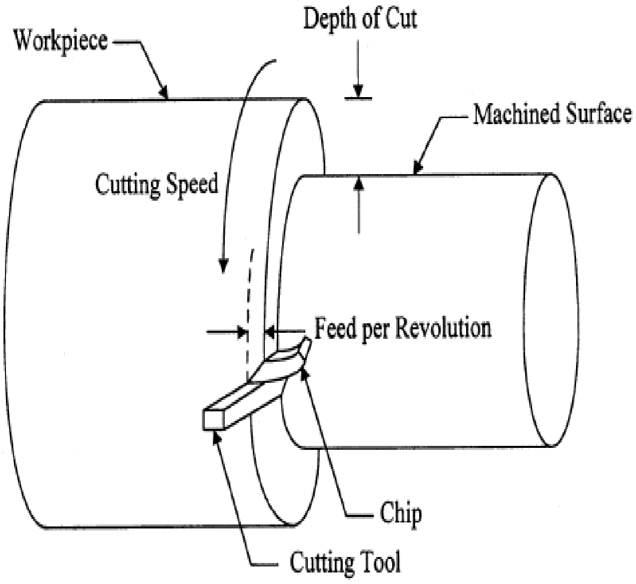

Figure 1. The adjustable machining parameters

II. EXPERIMENTAL PROCEDURE

A centre lathe was used to carry out the machining. The insert was clamped in a holder and mounted on the tool post. The job was held rigidly by the chuck of the lathe. Centre drilling was done and the job was held at the other end by the tail stock and a skin pass was carried out. The setup was hence complete and the runs could be carried out from here.

Dry cutting environment was used for the experimentation process. Dry cutting process is one that uses no coolant during machining. By the use of dry cutting, costs of cutting fluid were alleviated. Cutting fluids have corrosive effects and non-environment-friendly. Dry cutting reduces machining cost and is environment friendly. Also, inserts perform better at higher cutting temperatures achieved during dry cutting.

Design of experiments (DOE) is a structured method that is used to identify relationships between several input variables and output responses. With the help of DOE, the resources needed to carry out the experiment can be optimized [4]. Hence, it finds wide use in R & D studies. A few methods used as DOE are Taguchi Method, Response Surface Method and Factorial Designs. We will be focusing on the Response Surface Methodology during the ensuing study.

A new cutting edge was used for each run. The resulting tool wear was measured using a Toolmaker’s Microscope with digital read-out device [3].

The following table shows the levels of the cutting parameters chosen.

Table 1. Factors and levels for the Response Surface Study

Code	Parameter	Level (-1)	Level (+1)
A	Cutting Speed (m/min)	66	112
B	Feed (mm/rev)	0.05	0.15
C	Depth of cut (mm)	0.4	0.8

1. Response Surface Methodology (RSM)

Response Surface Method (RSM) is a collection of mathematical and statistical tools which are useful for the modeling and analysis of problems in which an output response of interest is influence by several input variables and our objective is to optimize (minimize or maximize based on the need) the response . It is a method which was developed by Box and Wilson in the early 1950‟s. It is capable of establishing causal relationships between input and output variables [2].

2. LAYOUT OF EXPERIMENT FOR RSM

The experiment layout was obtained in accordance with the 3-level full-factorial Central Composite Design with 8 cube points, 6 axial points, 4 centre points, and 2 centre points in axial, resulting in a total of 20 runs. α was chosen as 1 to make the design face centre.

III. RESULTS AND DISCUSSIONS

The main effects and interaction effects plots for the surface roughness shown in Fig:

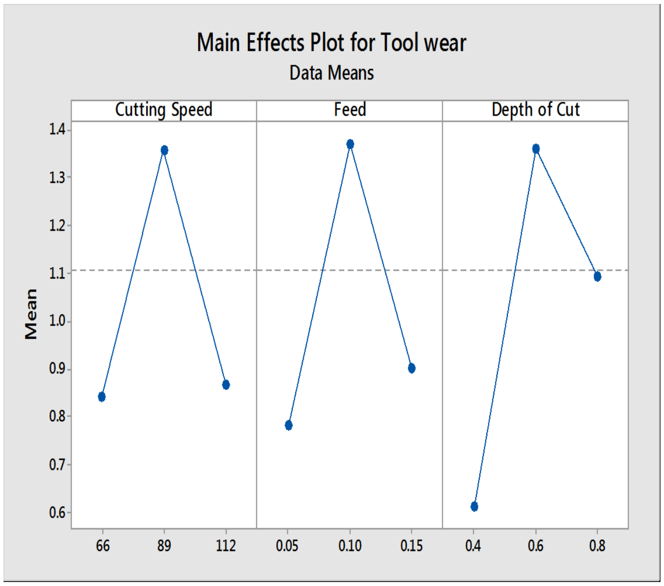

Figure 2. Main effects plot for Tool Wear

The main effects plot for tool wear tells us that a steep rise occurs in the tool wear for an increase in any one of the three parameters up to a certain level with other parameters kept constant. Wear decreases thereafter for rise in any one of cutting speed, feed, or depth of cut with other factors kept constant.

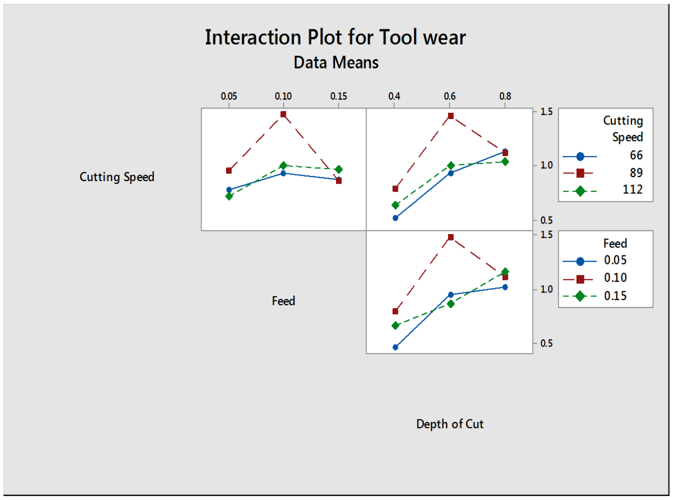

Figure 3. Interaction plot for Tool Wear

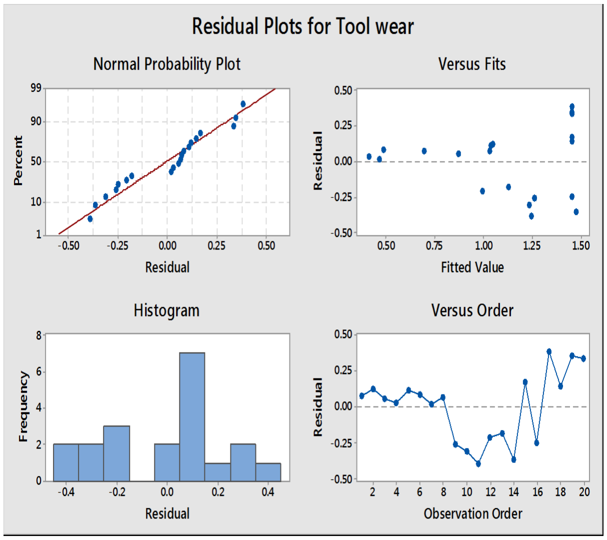

Figure 4. Residual Plots for Tool Wear

1. CONTOUR PLOTS AND 3-D SURFACE PLOTS

Use a contour plot to explore the potential relationship between three variables. Contour plots display the 3-dimensional relationship in two dimensions, with x- and y-factors (predictors) plotted on the x- and y-scales and response values represented by contours. A contour plot is like a topographical map in which x-, y-, and z-values are plotted instead of longitude, latitude, and elevation.3D surface and 3D wireframe plots are graphs that we can use to explore the potential relationship between three variables.

The predictor variables are displayed on the x- and y-scales, and the response (z) variable is represented by a smooth surface (3D surface plot) or a grid (3D wireframe plot).

Surface plots are diagrams of three-dimensional data. Rather than showing the individual data points, surface plots show a functional relationship between a designated dependent variable (Y), and two independent variables (X and Z). The plot is a companion plot to the contour plot. It is important to understand how these plots are constructed. A two- dimensional grid of X and Z is constructed.

Contour plots and 3-D surface plots for Tool wear are displayed in Fig.

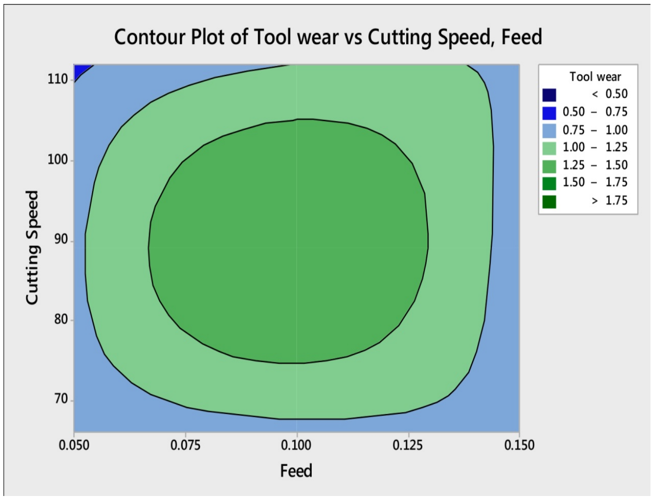

Figure 5. Contour plot of Tool Wear vs cutting speed, Feed

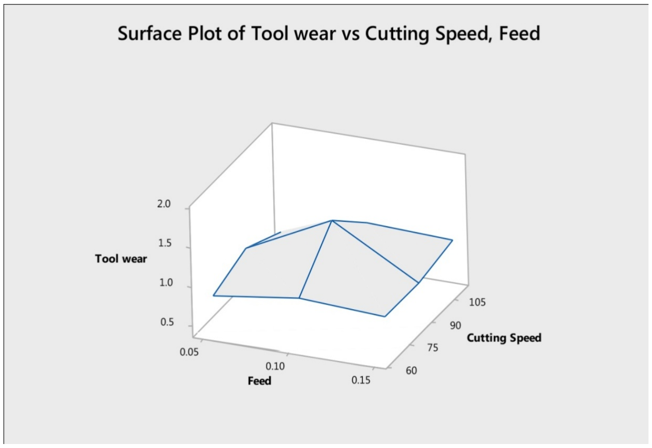

Figure 6. Surface plot of Tool Wear vs Cutting Speed, Feed

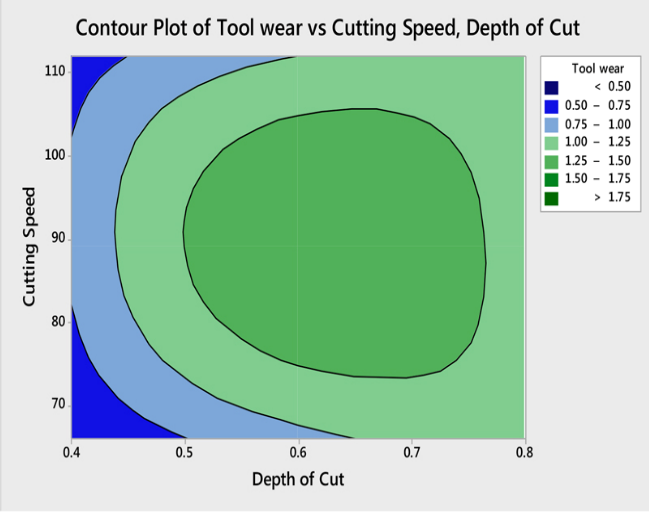

Figure 7. Contour plot of Tool Wear vs cutting speed, Depth of Cut

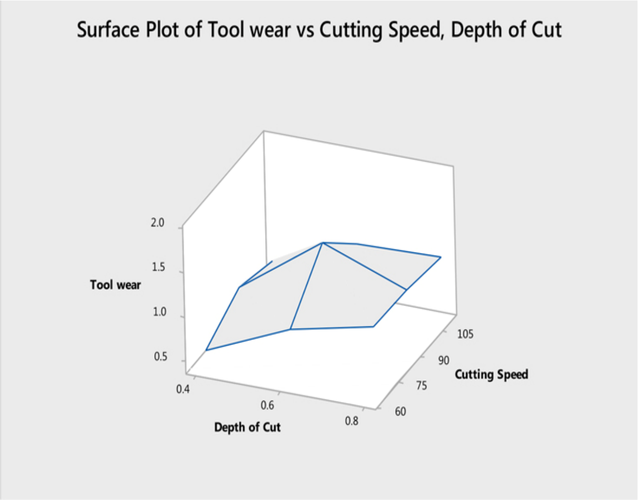

Figure 8. Surface plot of Tool Wear vs Cutting Speed, Depth of Cut

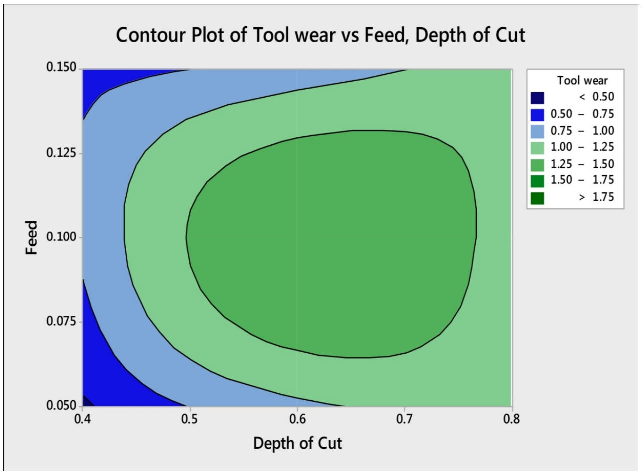

Figure 9. Contour plot of Tool Wear vs Feed, Depth of Cut

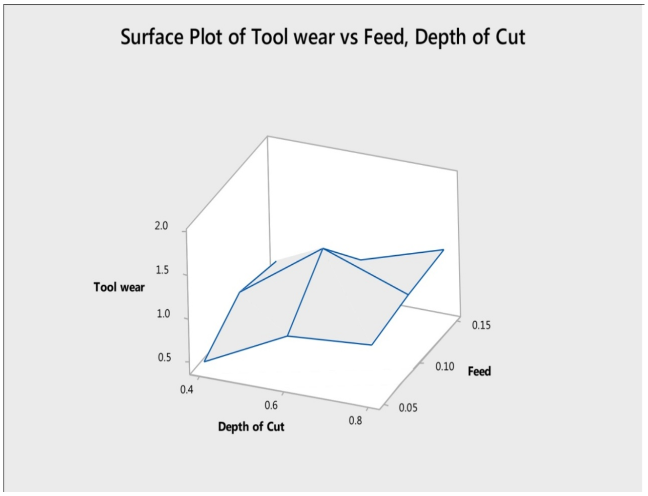

Figure 10. Surface plot of Tool Wear vs Cutting Speed, Depth of Cut

The above 3D surface and contour plots represent a response surface with a simple maximum. As the color gets darker, the response increases. Note the relationship between the shape of the surface and the shape of the contours. Both the surface and contour plots are based on a regression model.

The three best optimal settings are shown in Table 4.6 below. The best setting is found to be
Vc = 112 m/min, f = 0.0540404 mm/rev and d = 0.4 mm

Table 2.

Sol	Cutting Speed	Feed	Depth of Cut	Tool wear Fit
1	112	0.0540404	0.4	0.518828
2	66	0.0723647	0.410652	0.654968
3	66	0.062364	0.4	0.53775

IV. CONCLUSION

RSM was successfully applied in optimizing the tool wear for the chosen tool-work combination and for the selected domain of the input machining parameters. ANOVA analysis was carried out and it is observed that feed is the most significant factor affecting the tool wear, closely followed by cutting speed and depth of cut, while the only significant factor affecting the tool wear was found to be the depth of cut. The optimum running condition was found to be at V c (112 m/min), f (0.0540404 mm/rev) and d (0.4 mm). Empirical models for tool wear have been determined based on which predictions can be carried out for output responses for appropriate applications.

The experiment was originally planned to be conducted with the involvement of mist application of cutting fluid. Due to unavailability of the mist application device due to some constraints, the experiment was conducted in a dry cutting environment. Mist application of cutting fluid could be applied in the future to the same tool-work combination for the same domain of cutting parameters as chosen in the present study and its effects on the surface roughness and tool wear could be studied and analysed.

Another improvement that can be made to the present study is that cutting forces could be added as an output response in addition to surface roughness and tool wear. An attempt can then be made to find out optimum machining parameters so that multiple variables can be optimized via a single experimental trial.

Furthermore, any tool geometry parameter from among nose its effects on the output responses and in order to increase the effectiveness of the fitted model.

IV. ACKNOWLEDGEMENT

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