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EXPERIMENTATION AND PREDICTION OF THE WEAR OF A CUTTING TOOL IN TURNING PROCESS

In the present work, the performance of multilayer coated carbide tool was investigated considering the effect of cutting parameters during turning of 34CrMo4 Low alloy steel. It has high strength and creep strength, and good impact tenacity at low temperature. It can work at –110°C to 500°C. And EN 10083-1 34CrMo4 owns high static strength, impact tenacity, fatigue resistance, and hardenability; without overheating tendencies. The objective functions were selected in relation to the parameters of the cutting process: surface roughness criteria. The correlations between the cutting parameters and performance measures, like surface roughness, were established by multiple linear regression models. Highly significant parameters were determined by performing an Analysis of variance (ANOVA). During the experiments flank wear, cutting force and surface roughness value were measured throughout the tool life. The results have been compared with dry and wet-cooled turning. Analysis of variance factors of design and their interactions were studied for their significance. Finally, a model using multiple regression analysis between cutting speed, fee rate and depth of cut with the tool life was established.

Keywords: Turning, cutting parameters, tool wear, surface roughness, design of experiments

1. Introduction

In metal cutting process, the condition of the cutting tools plays a significant role in achieving consistent quality and also for controlling the overall cost of manufacturing. The design of cutting edge geometry and its influence on machining performance have been a research topic in metal cutting for a long time. Edge preparation has a critical effect on the tool life. A tool with poor edge preparation may chip and fail quickly [1]. The main problem caused during machining is due to the heat generation and the high temperature resulted from heat. The heat generation becomes more intensified in machining of hard materials because the machining process requires more energy than that in cutting a low strength material. As a result, the cutting temperatures in the tool and the work-piece rise significantly during machining of all materials [2]. At such elevated temperature the cutting tool if not enough hot hard may lose their form stability quickly or wear out rapidly resulting in increased cutting forces, dimensional inaccuracy of the product and shorter tool life. The magnitude of this cutting temperature increases, though in different degree, with the increase of cutting velocity, feed and depth of cut, as a result, high production machining is constrained by rise in temperature. This problem increases further with the increase in strength and hardness of the work material [2,3]. The experimental works on wear are come up against the difficulties of in situ mensuration of the contacts and the decoupling of the parameters which control this effect. To circumvent these difficulties, numerical simulations are built, and become a real tool for the comprehension of wear, first stage towards a predictive modeling. To do that that, the two solids in contact and the detached particles (third solid) are modeled by discrete elements validated with real experiments. The tool wear during machining depends on the combined effect of several factors which is the result of complicated physical, chemical and hermo-mechanical effects caused through the different mechanisms such as adhesion, abrasion, diffusion and oxidation [3]. Researchers have also investigated, experimentally, the effect of process parameters (namely residual stresses and white layer formation) on cutting forces and surface integrity. White layers in micro-structures of surface layers of machine-hardened steels are observed. Because the hard-turning process boasts several advantages over the grinding process, researchers have paid considerable attention to the machining of hardened steels, working with materials of hardness ranging from 45 to 65 HRC Asilturk and al [5], Grzesik and al [6] explored the mechanisms of wear occurring with the mixed ceramic inserts during the hard machining of AISI 5140 having a hardness of 60 HRC. Grzesik and al [6] considered both microscopic and microstructural aspects, such as abrasion, fracture, plastic flow, adhesive tacking, and material transfer. In conventional machining, the process of tool wear consists of three stages. These are rapid initial wear, gradual intermediate wear, and finally very rapid wear or catastrophic wear. When the critical value of the tool wear criterion has been reached, the tool fails due to excessive

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stresses and thermal alterations caused by large friction forces. To avoid this, the cutting tool must be replaced before reaching its critical limit. However, this approach has two typical shortcomings. The first one is that a worn tool will produce out-of specification parts or even cause catastrophic tool breakage. The second one is the fact that if the tool is dismissed prematurely, the direct consequence will be a significant waste of manufacturing resources. During milling process, the cutting edges periodically enter and exit the work piece [7]. The aim of the present work is, thus, to model surface roughness in hard turning of 34CrMo4. 17 machining tests were carried out under dry conditions with the multilayer coated carbide TNMG 220408 inserts using Taguchi method.

The model predicting equations for cutting force and surface roughness were developed. To calculate constants and coefficients of these models, the software's MODDE characterized by analysis of variance (ANOVA), multiple linear regression and response surface methodology (RSM) were exploited.

In order to achieve this: statistical analysis of the experimental, the analysis of variance (ANOVA) was applied. This latter is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. In this work, the parameters were used to develop mathematical model using multiple linear regression and response surface methodology (RSM). RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which response of interest is influenced by several variables and the objective is to optimize the response [8-9].

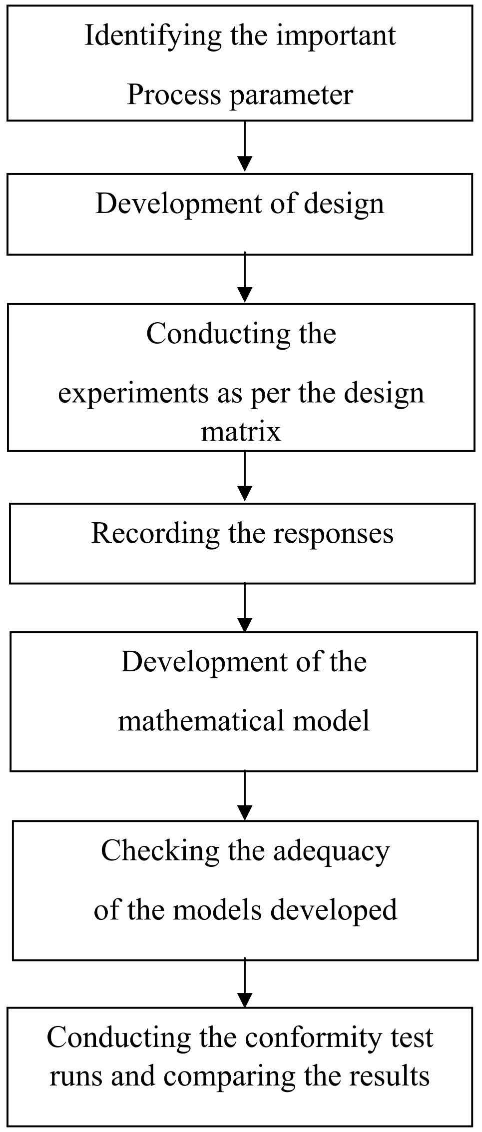


Fig. 1. Methodology of optimization

2. Materials and methods

2.1. Experimental designs

Response surface methodology is the most effective method to analyze the results obtained from factorial experiments. It is an effective tool for modeling and analyzing the engineering problems. It provides more information with less number of experimentation. In most of the RSM problems, the form of the relationship between the response and the independent variables is unknown [10]. The Fig. 1 flow chart has given to understand the methodology used to study the effect of important parameters:

In the present work, cutting speed, feed rate, depths of cut have been considered as the machining parameters. The response wear can be expressed as a function of process parameters cutting speed, feed rate and depth of cut.

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_{12} x_1 x_2 \quad (1)$$

2.2. Mathematical modeling

The general form of a quadratic polynomial which gives the relation between response surface 'y' and the process variable 'x' under investigation is given in equation. The values of the coefficients of the polynomials were calculated by multiple regression method.

The second order mathematical model was developed by neglecting the insignificant coefficients of the tool wear are given in Eq (2). In the experimental research, modeling and adaptive control of multifactor processes the RCCD of experiments is very often used because it offers the possibility of optimization [11].

$$wear = a_0 + \sum_{i=1}^{3} a_i x_i + \sum_{1 \le i < j \le 3} a_{ij} x_i x_j + \sum_{i=1}^{4} a_{ii} x_i^2 + e \quad (2)$$

Where a_0, a_i, a_{ij}, a_{ii} are regression coefficients, and x_i, x_j are the coded values of input parameters.

2.3. Experimental setup

The experiments were realized in dry straight turning operation using lathe type SN 40 with 6.6 KW spindle power and

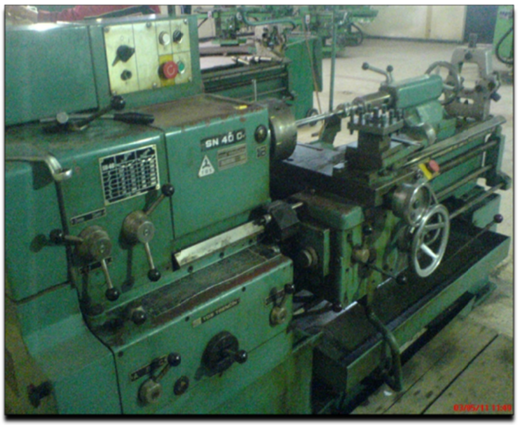


Fig. 2. Conventional lathe SN 40C

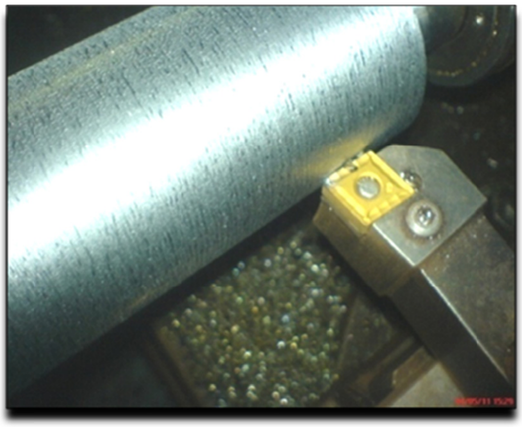


Fig. 3. Work piece material 34CrMo4

capability of 22-2000 rev/min (Fig. 2) and A34CrMo4 (Fig. 3) bearing steel as work piece material with round bars form (44 mm diameter and 240 mm length) and with the following chemical composition: 0.31%C, 0.72%Mn, 0.4%Si, 0.025%P, 0.035%S, 0.18%Mo and 1%Cr.

A deformation of 30% (broken-line) shows, just as much an increase to 60% (dotted-line), merely slight changes of the transformation behaviour except for a rise of the martensite start-temperature. This is also demonstrated by the small changes of hardness values for increasing deformation. A comparison of the microstructural components formed for different deformations shows a slight retardation in the bainite formation and, as a consequence, a smaller fraction of pearlite for a cooling rate of 0.3 K s^{-1} (Fig. 4).

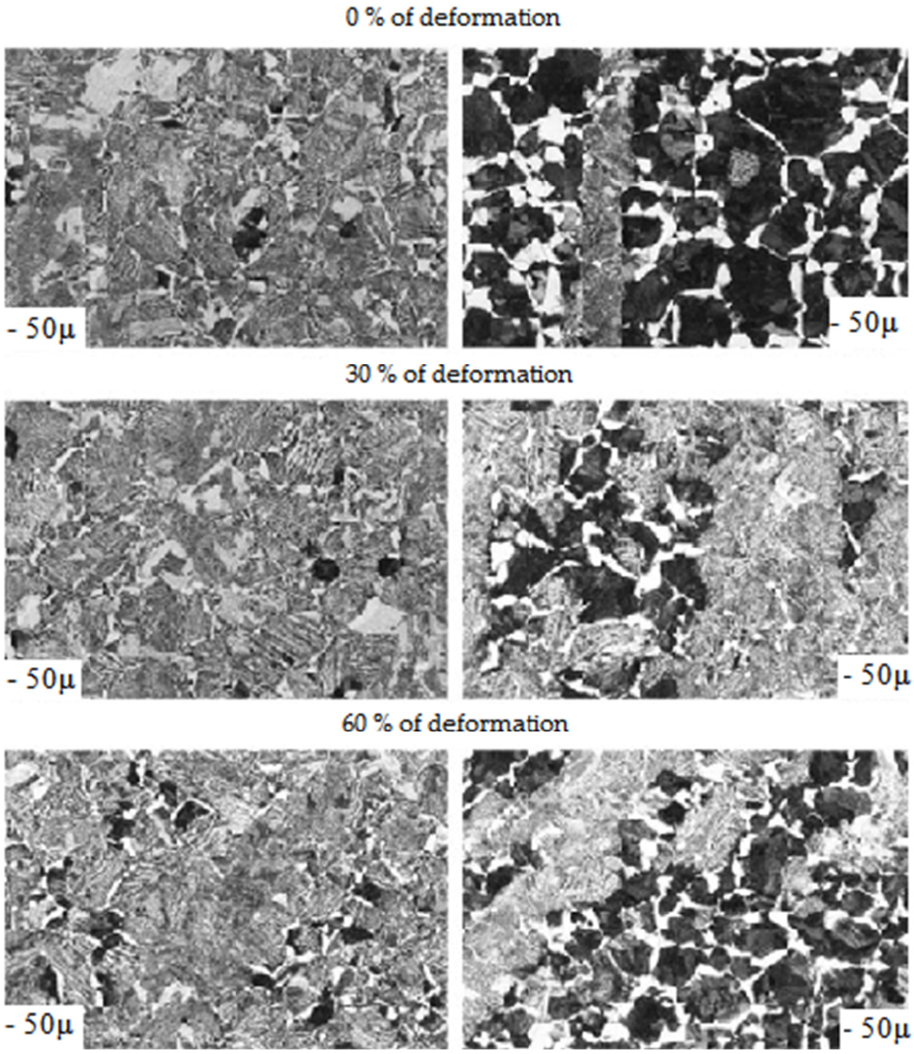


Fig. 4. Microstructure of 34Cr Mo4

At this cooling rate, the pearlitic structures slightly decrease in size with the deformation level. In contrast, the almost identical microstructures are shown for the cooling rate of 0.6 K s^{-1} and varied deformation levels for comparison [12].

TNMG 220408 GS US15 Carbide Inserts for Turning PVD Coated Grade US15 (S15-M20 + Multi layer PVD Coating) Main application Hi-temp Alloys, Inconel, Titanium Alloys and Stainless Steel under difficult conditions (Fig. 5). The parameters to be studied and the attribution of the respective levels are indicated in table 1.

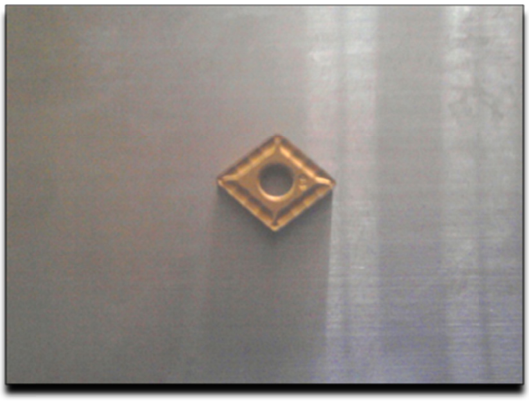


Fig. 5. Tool TNMG 220408Carbide Inserts

TABLE 1

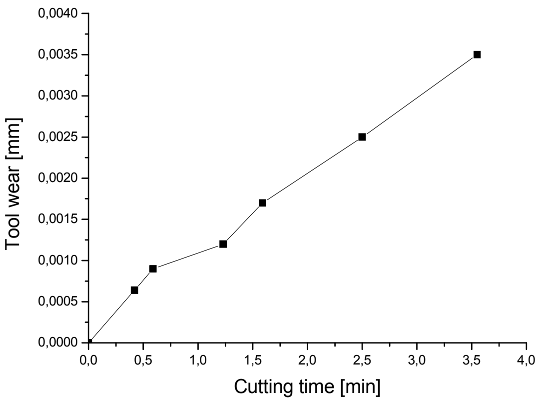
Cutting parameters and their levels

Level	**Spindle speed N (rev/min)**	**Feed rate *f* (mm/rev)**	**Depth of cut *ap* (mm)**
1	90	0.32	0.25
2	125	0.48	0.35
3	180	0.64	0.425
4	250	0.88	0.55
5	355	1.12	0.6
6	500	1.28	0.7

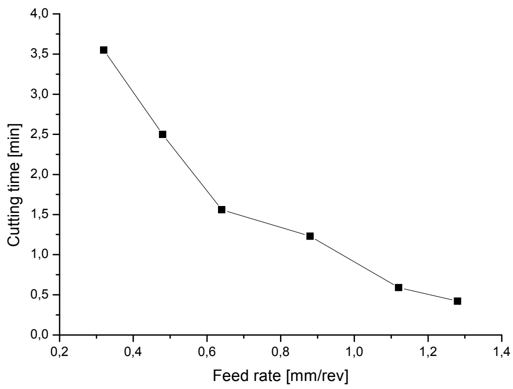
3. Results and discussions

3.1. Tool wear and flank wear

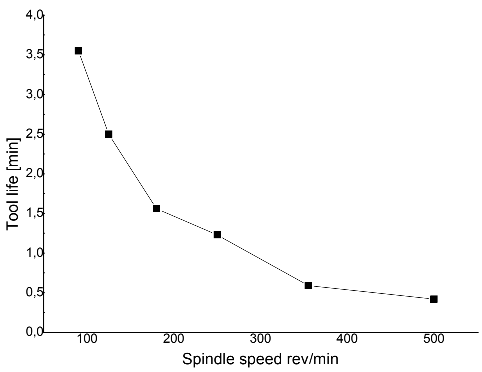
The examination of the process of the tool point wear particularly in industrial processes showed that the most common type of wear was the average and maximum wear bandwidth of abrasive wear on the major flank (Fig. 6). With the progress of machining, the tools attain crater wear at the rake surface and flank wear (Fig. 7) at the clearance surfaces [2], the principal flank wear is the most important because it raises the cutting forces and the related problems. (Fig. 6a) illustrates a typical



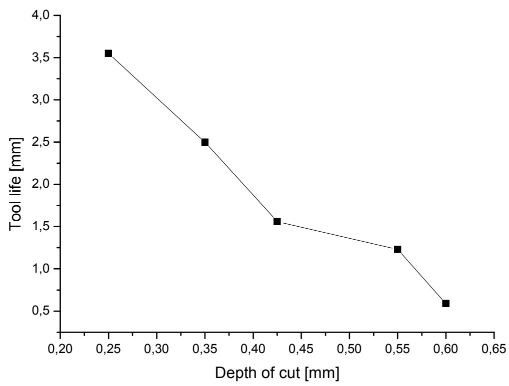
(a) Flank wear vs. cutting time



(b) Tool life recorded in dry machining with coated carbide tools



(c) Effect of spindle speed on life of tool at constant feed rate of 0.32 mm/rev



(d) Effect of depth of cut on life of tool

Fig. 6. Typical parametric influences on life of tool

(a) Crater wear (b) Flank wear

Fig. 7. Effect of cutting parameters on flank wear

flank wear versus cutting time behavior obtained during finish hard turning 34CrMo4 steel for different combinations of low and high cutting parameters levels. According to ISO standard to tool life testing, the life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value of its principal flank wear reaches a limiting value of 0.0035 mm. (Fig. 6b) illustrates the tool life at different cutting speeds and constant depths of cut at 0.25 mm with dry turning. When cutting speed increases, tool life decreases as is expected. But, tool life more decreases for wet cutting than dry cutting. (Fig. 6c) show the effect of spindle speeds of 90, 125, 180, 250, 355 and 500 rev/min on life of tools for value of the feed rate of 0.32 mm/rev. As the spindle speed increased from 90 rev/min up to 500 rev/min, the tool life reduced from 3.55 min to 0.42 min, approximately 85 % reduction in tool life at constant feed of 0.32 mm/rev. It can be seen that better tool life is obtained with a combination of spindle speed 90 rev/min and feed 0.32 mm/rev. This agrees with [13], which had earlier discovered that better tool life is obtained in lowest feed rate and lowest cutting speed combination. When the depth of cut increases and the uncut chip thickness is kept the same, the specific contact stresses at the tool–chip interfaces, the chip compression ratio (defined as the radio of the chip and the uncut chip thicknesses) [14], and the average contact temperature remain unchanged. Therefore, an increase in the depth of cut should not change the tool wear rate if the machining is carried out at the optimum cutting regime. (Fig. 6d) show the effect of depth of cut (0.25, 0.35, 0.42, 0.55 and 0.6 mm) on life of tool for value of the constant spindle speed (500 rev/min). As the depth of cut increased from 0.25 to 0.6 mm, the tool life reduced from 3.55 min to 0.42 min at constant spindle speed 500 rev/min. This is as a result of lower spindle speed that cannot enhance increase in cutting force at the cutting zone as the depth of cut increases. More materials will have to be cut which means more energy will be required and this will cause an increase in the cutting force and hence, decrease tool life.

In the experiments, PVD coated carbide cutting tool was taken into consideration throughout the tool life at certain cutting conditions. Parameter on tool life was determined with respect to the recommendations advised by the tool manufacturers for the coated tools. For all tools, only the flank wear was taken into consideration in the comparisons. The result of experimental data is given in table 2.

TABLE 2

Results of experimental data

N°	Feed rate *f* (mm/rev)	Spindle speed N (rev/min)	Depth of cut *ap* (mm)	Flank wear (mm)
1	0.32	90	0.25	0.0003
2	1.28	90	0.25	0.0005
3	0.32	500	0.25	0.0005
4	1.28	500	0.25	0.0008
5	0.32	90	0.6	0.0007
6	1.28	90	0.6	0.0011
7	0.32	500	0.6	0.0008
8	1.28	500	0.6	0.0013
9	0.32	295	0.425	0.0004
10	1.28	295	0.425	0.0009
11	0.8	90	0.425	0.0007
12	0.8	500	0.425	0.00012
13	0.8	295	0.25	0.0008
14	0.8	295	0.6	0.0011
15	0.8	295	0.425	0.0009
16	0.8	295	0.425	0.0009
17	0.8	295	0.425	0.0009

Tool wear is one of the most important criterions for machinability assessment of the cutting process, while surface roughness has widely been considered to be primary indicator of the machined surface quality. In the current work, the experimental matrix and the values of the response factors for the flank wear have achieved during machining of 34CrMo4 steel (table 2).

The flank wear values were obtained in the order from 0.0003 mm to 0.0011 mm. These results, in turn, are served to calculate the statistical analysis of variables for the cutting parameters in order to find the most significant affected cutting parameters with respect to the response factors.

3.2. Appearance of chips form at various cutting conditions

Fig. 8 shows chip forms obtained at different cutting conditions. At spindle speed 90 rev/min and 0.32 mm/rev with 0.25 mm depth of cut the chips formed were very long, formed in curls (Fig. 8a).

The diameter of the curl was found to increase with the feed rate. As the cutting edge of the tool approaches the work piece material, it gets compressed because of the relative motion of the tool and work piece and reaches a plastic state. This initiates the chip formation along the rake face of the tool. Thus a finite thickness of the work piece gets sheared across the shear plane in a continuous manner resulting in the formation of lengthy chips. The change in form of chips as the cutting speed increases is due to increased ductility of the work material because of the high machining temperature at higher cutting speeds. For lower cutting speeds segmented chips were obtained. When the cutting edge of the tool approaches the work piece, the work piece material gets severely compressed resulting in high strain. Because of this strain hardening and the fact that the material deforms plastically beyond a critical stated is continuous segmented chips were formed .The material behaves like a brittle material when machining at lower spindle speeds. More over brittle type of failure was more predominant [15].

Machining materials in dry condition produced tubular with helical shape type chips at speed rates of 180 rpm and 500 rev/min given respectively in Fig. 8b and Fig. 8e. It can be explain that chip tool interface temperature increase with increasing the speed, feed rates and also due to the friction and adhesion between chip tool tend to be higher temperature in dry machining increases ductility of the work piece due to high temperature as well as tool without chip breaker, it is difficult break the chips at tool and wok interface area which produce the chips in to tubular form at lower speeds and continuous tubular and ribbon form at higher speeds. Examining the chips that are corning off a work piece will give a lot of information as to how well the job is going, how tool wear is progressing, and why premature tool failure or short

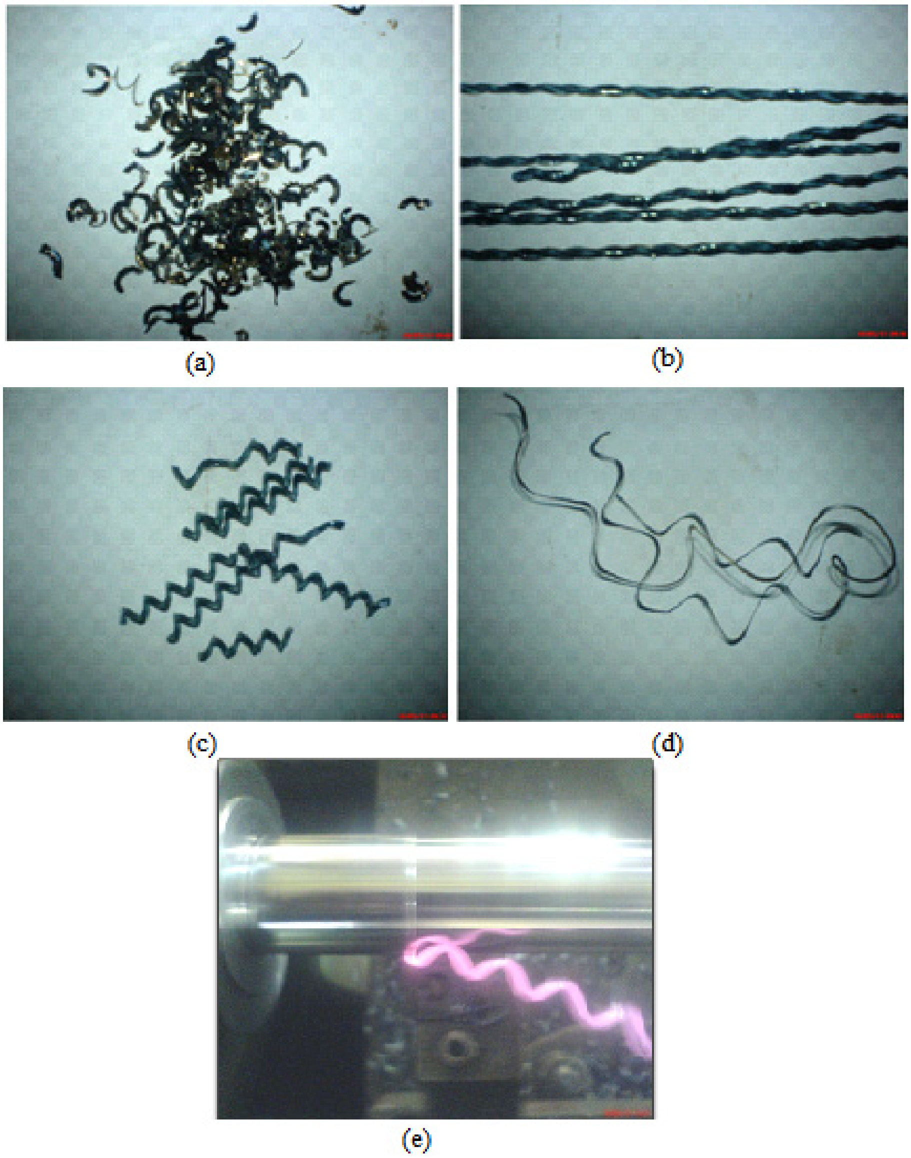


Fig. 8. Various type of chips formation

tool life is occurring. As crater wear grows further its effect as the chip breaker becomes more significant until a fully-utilized chip breaker is realized which breaks chips in the most effective way as seen at $N = 250$ rev/min (Fig. 8c). Further growth of crater wear over sizes the chip breaker, resulting in the increase of chip curling curvature which lowers chip breakability.

Basically, the chip forms were a snarled washer type helical chip despite having been obtained at the spindle speed of 355 rev/min and various feed rates (Fig. 8 d). This was attributed to be due to the constant and low depth of cut that was used throughout. The chips obtained were basically continuous chips and was possibly influenced by the stress, strain, and temperature gradients which remained constant with respect to time; that is to say, a steady-state condition is reached [16].

Fig. 9. Poor surface finish

3.3. Analysis of the developed mathematical model for flank wear

In this paper, the effect of cutting parameters towards the flank wears during machining of 34CrMo4 steel is first investigated based on the Analysis of Variance; which is one of the most useful statistical model. By applying regression analysis the coefficients of regression, multi-regression factors, standard false evaluation and the value of the test have been assessed. After omitting insignificant factors the mathematical model for tool wear is obtained as follows:

$$\begin{aligned} Tool\,wear &= 0.0035 + 0,00039 * V_f + 0.0047 * N + \\ &+ 0.00021 * a_p - 0.0001 * V_{f^2} - 7.038e^{-7} * N^2 + \\ &- 0.0004e^{-5} * a_{p^2} - 8,74e^{-5} * V_f * N + \\ &+ 1.25e^{-5} * V_f * a_p - 0.00013e^{-5} * N * a_p \qquad (3) \end{aligned}$$

A poor surface finish due to tool wear is shown in Fig. 9. The presence of graphitic film in the composite greatly influences the surface roughness while machining. The major reason for this is the reduction in coefficient of friction at the tool work piece interface resulting in the cutting of material. Graphite particles being less dense and soft were easily smeared on the work piece surface. This results in the formation of pits and valleys which in turn leads to poor surface roughness [15].

The normal probability plot of residuals as shown in Fig. 10 also lies fairly close to a straight line suggesting that the errors are normally distributed and the regression model well fitted with the observed values.

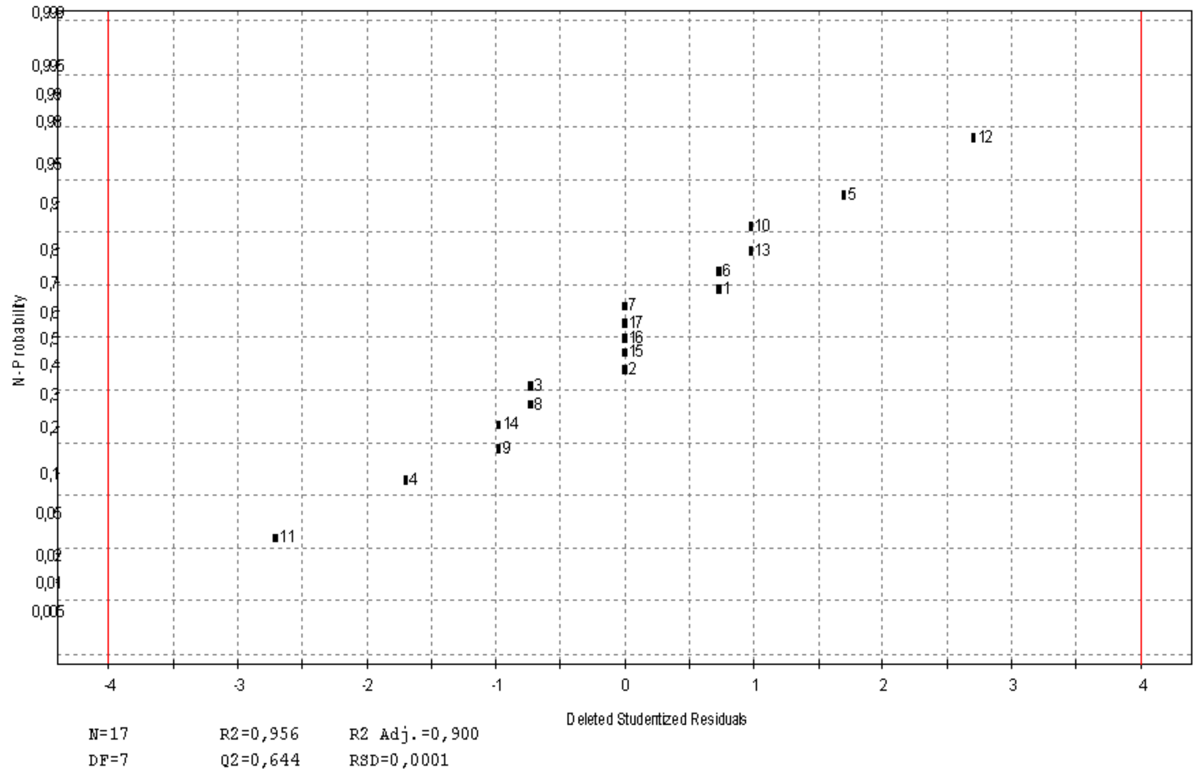


Fig. 10. Normal probability plot of regression

3.4. Optimizing parameters

The effects of spindle speed (*N*), depth of cut (a_p) and feed rate (*f*) on flank wear as predicted by equation (3). Strong interactions were observed between process parameters for tool wear, the most significant interaction effects were analyzed. The regression mathematical model has been used to plot interaction graphs for different combinations of machining parameters and effects were analyzed.

The analysis of variance results showed that linear terms spindle speed, feed and depth of cut are significantly influence on Tool wear. These can be seen in the main effect plot of tool wear. Tool wear has increased rapidly with increasing of spindle speed and depth of cut. It can be observed that the interaction effect of different cutting parameters have significant influence on tool wear [17]. Further, the model adequately explains the total variance in cutting parameters and it is also reasonably a good fit (R2 = 95.60% R2 adj. = 90%) (Table 4). It can also be noted through analysis of variance that tool wear is not significantly influenced due to the interaction between speed and depth of cut; however, there is an indication that at higher speed the influence may be significant figure 11 shows the interaction plot. The effect of feed rate on tool wear is displayed in Fig. 11a.

The larger the feed, the greater is the cutting force per unit area of chip-tool contact on the rake face and work –tool contact on the flank face. Cutting temperatures and therefore the different types of wear are increased. An increase in cutting force as a result of larger feed also increases the likelihood of chipping of the cutting edge through mechanical shock. It has, however been observed that the effect of changes in feed on tool life is relatively smaller than that of proportionate changes in cutting speed. (Fig. 11b) exhibits the effect of depth of cut on tool wear. If the depth of cut is increased, the area of the chip-tool contact increases roughly in equal proportion to the change in depth of cut. Consequently the rise in tool temperature is relatively small. That is not the case when feed is changed. In that case, the proportionate change in temperature is larger. This is on account of the fact that the area of chip-tool changes by a smaller proportion than the change in feed rate. Thus, an increase in depth of cut shortens tool life to some extent by accelerating the abrasive adhesive and diffusion types of tool wear. The effects of speed on the tool wear as shown in Fig. 11 c.

As the cutting speed is increased up to a certain limit, a brittle fracture occurs at the cutting edge rather than a gradual flank wear and the depth of the cracks on the cutting edge increases rapidly resulting in a catastrophic failure of the tool. When the cutting speed is comparatively low, the size and depth of the crack on the flank is very small. Crack grows rapidly at higher cutting speeds. The cutting force on the tool edge increases as the cutting speed is increased. Higher cutting speed increases tool temperature and softens material. It thereby aids abrasive, adhesive and diffusion wear.

3.4.1. Interaction effect of feed rate and spindle speed on tool wear

Based on the mathematical model given by equation (3) developed through experimental observations and response surface methodology, studies have been made to analyze the effect of the various process parameters on the flank wear. The contour plots were drawn for various combinations. The number represent in the plot is flank wear.

In Fig. 12, it is clear that the flank wear increases with the increase in the spindle speed (N). At lower spindle speed, flank wear is lesser extent, which can be attributed to formation of larger size unstable due to high contact pressure and friction which protects the cutting edge from further wear [18].

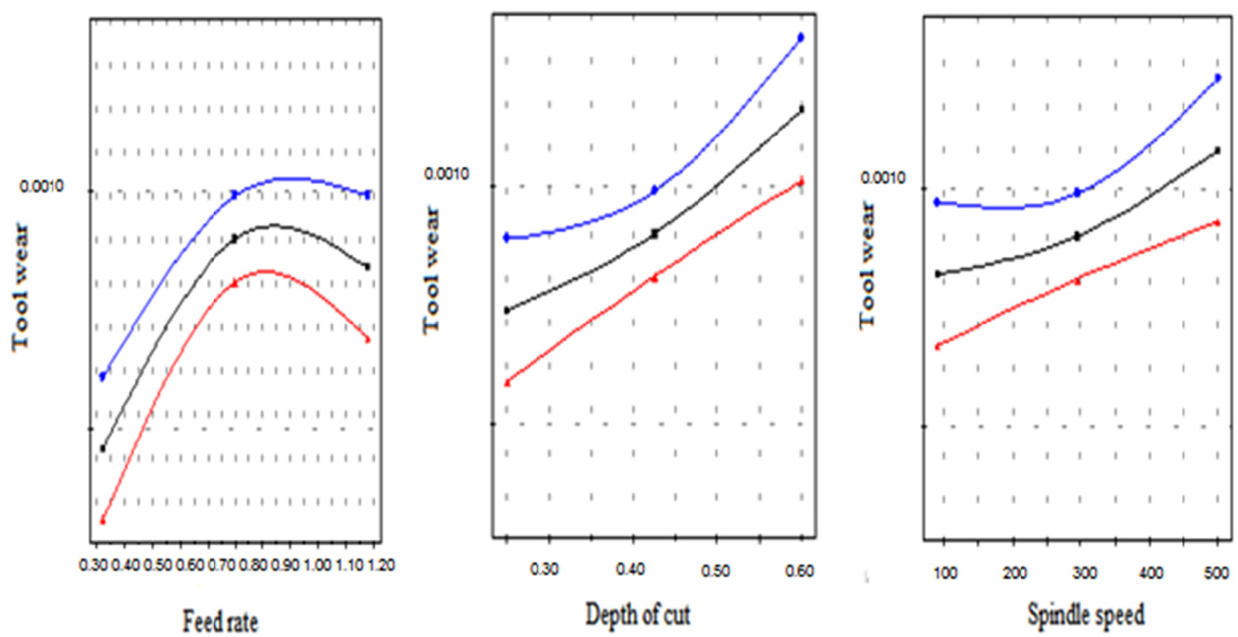


Fig. 11. Main effects plot for Tool Wear

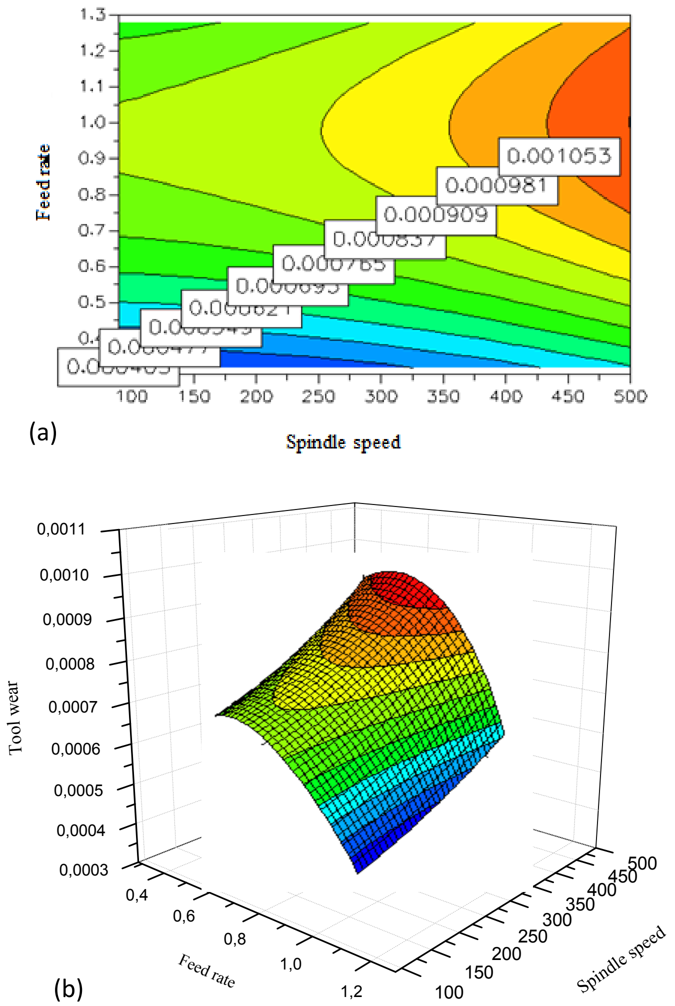


Fig. 12. Effect of feed rate and spindle speed on tool wear

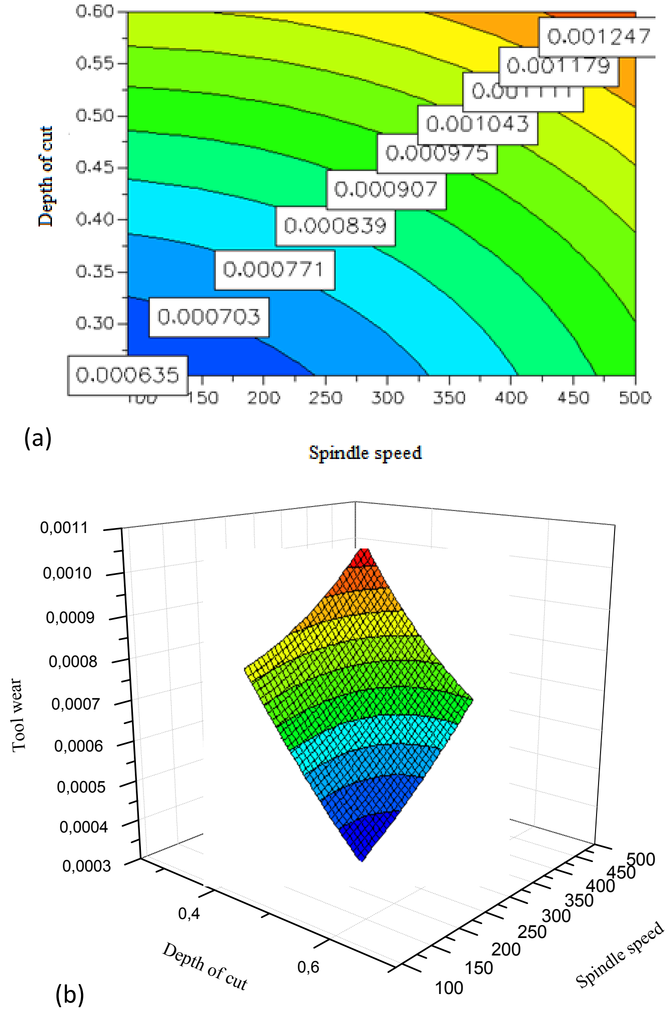


Fig. 13. Effect of spindle speed and depth of cut on tool wear

But with increase in spindle speed, an increase in tool flank wear is observed which could be due to generation of higher temperature at higher spindle speed and associated thermal softening and deterioration of form stability of the cutting edge; also, the flank wear increases with increase in feed rate. It is due to built-up edge (BUE) formed on flank face that changes the geometry of the tool.

3.4.2. Interaction effect of spindle speed and depth of cut on tool wear

Fig. 13 shows the effect of spindle speed and depth of cut on flank wear. Increasing the depth of cut increases the flank wear due to increase in area of contact, normal load, and friction. This, in turn, increases temperature, which will cause work softening and thus results slight increase in flank wear. The spindle speed and the depth of cut varies and the feed rate kept at 0.32 mm/rev. From Fig. 13, tool wear decreases for all the three depth of cut as the spindle speed is increased from 90 to 500 rev/min. This decreasing trend is not changed in all three levels of depth of cut. Hence the interaction effect of spindle speed and depth of cut is less significant.

3.4.3. Interaction effect of feed rate and depth of cut on tool wear

Fig. 14 shows the interaction effect of feed rate and depth of cut on tool wear. It is clear that the tool wear increases with an increase in feed rate ranging from 0.3 mm/rev to 1.28 mm/rev. The same trend continues for depth of cut value which is increased from 0.2 mm to 0.6 mm. When the depth of cut is lower, there is less work piece material adhered to the flank than at larger depth of cut. Since the heat and the forces generated during the cutting process are higher at larger depth of cut, it is reported that the higher temperature and the higher force are the main reasons that cause the adhesion of work piece material onto the tool flank face, thus accelerating the tool wear.

The predicted and the experimental results are found to be very close as may be seen from Fig. 10 and table 3. It shows the comparison of predicted vs experimental value of tool wear for the cutting parameters. The percentage of error is found to be within ±3% which shows the validity of the model. The optimized values of process parameters are spindle speed (N) 90 rev/min feed rate (f) 0.32 mm/rev and depth of cut (a_p) 0.25 mm.

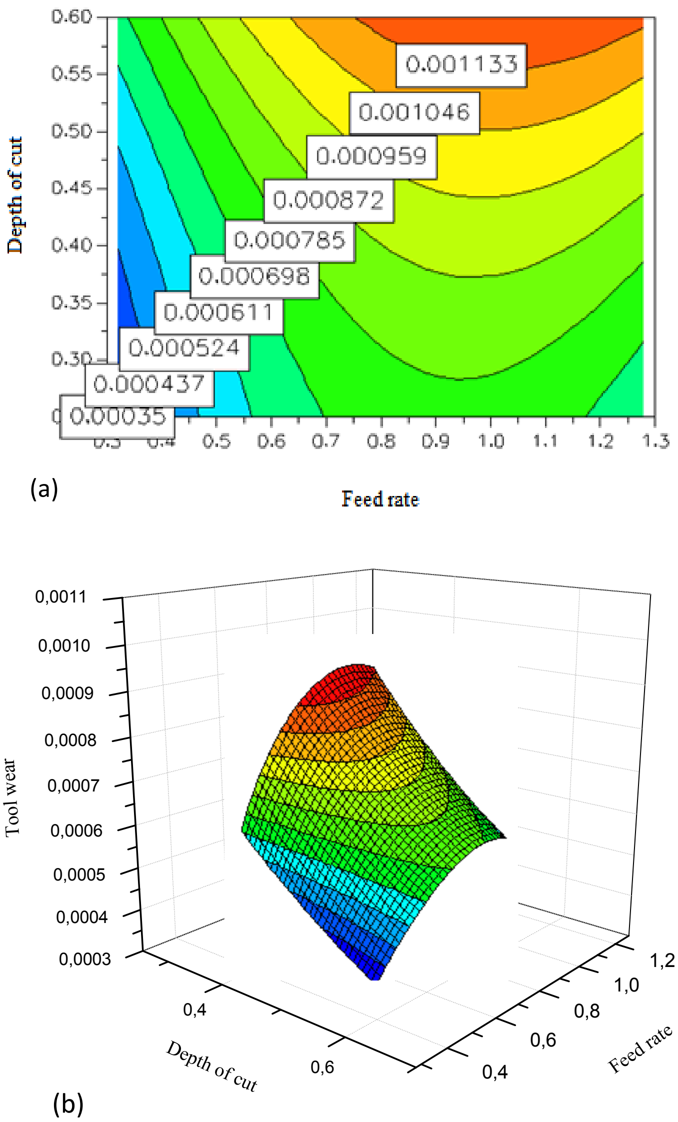


Fig. 14. Effect of feed rate and depth of cut on tool wear

TABLE 3

Optimization result

Feed rate f (mm/rev)	Spindle speed N (rev/min)	Depth of cut ap (mm)	Tool wear (mm)
0.32	90.4466	0.2501	0.0003
1.28	90	0.25	0.0005
0.32	90.0485	0.25	0.0003
1.1547	90.0023	0.2501	0.0006
0.32	368.981	0.25	0.0004
0.32	90	0.25	0.0003
1.28	90	0.25	0.0005
0.32	142.276	0.25	0.0003

4. Conclusions

In the present study, ANOVA and RSM approaches were used to predict tool wear during turning of 34CrMo4 steel having a hardness of 187HB. The effect of various machining parameters such as spindle speed, feed rate and depth of cut in the machining process were investigated on the quality of machined surface and the wear of the TNMG 220408 Carbide cutting tool. The ranges of machining parameters studied in this research are spindle speeds of 90, 125, 180, 250, 355 and 500 rev/min, feed rates of 0.32, 0.48, 0.64, 0.88, 1.12 and 1.28 mm/rev and depths of cut of 0. 25, 0.35, 0.425, 0.55, 0.6 and 0.7 mm.

TABLE 4

Estimated Regression Coefficients for Tool Wear

Term	Coeff. SC	Std. Err	P	Conf. Int (±)
Constant	0.0009	3.75829^{e-005}	5.6314^{e-008}	8.88706^{e-005}
V_f	0.00019	2.77746^{e-005}	0.000244015	6.56774^{e-005}
N	0.00013	2.77746^{e-005}	0.00225942	6.56774^{e-005}
a_p	0.00021	2.77746^{e-005}	0.000130472	6.56774^{e-005}
$V_f * V_f$	–0.00025	5.36589^{e-005}	0.00231707	0.000126885
$N * N$	5^{e-005}	5.36589^{e-005}	0.382447	0.000126885
$a_p * a_p$	4.99999^{e-005}	5.36589^{e-005}	0.382448	0.000126885
$V_f * N$	2.5^{e-005}	3.1053^{e-005}	0.447253	7.34295^{e-005}
$V_f * a_p$	5^{e-005}	3.1053^{e-005}	0.1514	7.34295^{e-005}
$N * a_p$	–2.50001^{e-005}	4.99999^{e-005}	0.447253	7.34295^{e-005}

N = 17 Q2 = 0.644
Cond. no = 4.4382
DF = 17 R2 = 0.956
Y – miss = 0
R2 Adj = 0.900 RSD = 0.0001
Conf. lev = 0.95

The data obtained were used to develop tool wear models. From the present study, the following conclusions were drawn:

- Response Surface Methodology (RSM) can predict tool wear better than Design of Experiments and Analysis of Variance (ANOVA).
- These results indicate that tool wear is significantly influenced by spindle speed, feed rate, and depth of cut.
- Finally the experimental results show that the response surface method is one of the best methods for prediction the model for metal cutting.

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