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PERFORMANCE STUDIES OF VANADIS23 TOOL IN TURNING USING TAGUCHI METHOD

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Abstract: The powder metallurgy tool steel Vanadis23 is studied in this research work. In a heat treatment a combination of heating and cooling operations timed and applied to a metal or alloy in the solid state in a way that will produce desired properties. In the machining operation life of tool is of prime importance. Tool life is mainly related to the tool wear. Tool life in a production operation depends on the part geometry and requirements, cutting conditions and in some cases on machine tool and tool holder characteristics hence for realistic estimates of tool life in practice generally be obtained only from production test results or experience. In this paper an attempt is made to study the effect of heat treatment on wear and a proposal of a mathematical model to evaluate the wear of Va*nadis23 PM steel tool. For this Taguchi's OA method is used to* finalize the experiments.

Key Words: Heat treatment, Tool wear, Tool life, Vanadis23 PM steel tool, Taguchi OA,

1. INTRODUCTION:

The powder metallurgical (PM) route was chosen because segregation-free and more homogeneous microstructures with a more cleanness can be achieved in comparison to a conventional metallurgical (IM) route. Different mechanical properties can be achieved by PM method which depends on whether samples were taken parallel or perpendicular to the direction of hot deformation. As well, PM tool steels provide uniform spacing between single carbides in all directions [1].

Tool life is a time period in minute between two successive grindings. Tool life is mainly related to the tool wear. Performance of a tool is based on material of tool, work material and cutting conditions or environment. Cutting tools have a limited life because of wear. There are mainly two types of wear related to tool i.e. flank and crater wear. There are various tool materials used in metal cutting industries among them are HSS, alloy steel, cemented carbides, coatings of hard materials, ceramic etc. But HSS is predominantly widely used tool material in industries till date. Flank and crater wear are the most important and thus the most widely measured forms of tool wear. Flank wear is most commonly used for tool wear monitoring since it occurs in virtually all machining operation. F. W. Taylor has been shown the relationship between tool life and cutting speed. Cutting speed, feed and depth of cut are parameters that effect on the tool life. But cutting speed is main factors which affect on the tool life as it produce more heat and increase temperature at cutting zone. As temperature at cutting zone increases wear of tool increases thereby reducing the tool life. An attempt is made in this paper to propose a mathematical model to evaluate the wear of Vanadis23 PM steel tool related to turning parameters. For this Taguchi's orthogonal array method is used to finalize number of experiments [2,3].

2. LITERATURE REVIEW:

Flank wear is the most significant tool wear occurring in machining operations. Flank wear is primarily attributed to the rubbing of the tool along the mechanical surfaces, which causes abrasive, diffusive and adhesive wear mechanisms. In addition, the high temperatures produced affect the tool material properties as well as the work piece surface [4]. The factors which affect on flank wear of tool are material of tool and work piece, tool geometry, cutting parameters as well as different treatments given to the tool materials. From these factors if material of tool and work piece, tool geometry, cutting fluid, machine, and other parameters are kept same then tool wear indirectly tool life can be considered dependent on process parameters viz cutting speed, feed and depth of cut and the tool treatment given to the tool material [3]. There is a standard procedure of tool life testing. The purpose of these standards is to combine tool life testing procedures so that increase in reliability and comparison of tests results while comparing cutting material of tool and work piece, process parameters, cutting fluids and various treatment applied to tool materials[5].

From the literature referred it is seen that many authors applied efforts to optimize tool life with the help of various optimization methods. The output response obtained and the input parameters were taken into account to establish the relationship between them using regression analysis.

S. K.Choudhury and K. K. Kishore [6] to validate the mathematical model developed for predicting tool wear and establish the effects of cutting speed, feed, depth of cut, work piece diameter and force ratio conducted a series of experiments using C45 as work piece and HSS tool. For this, the 3^3factorial design was implemented and 27 experiments were conducted. From the comparison of experimental and predicted values of tool flank wear they found that a good agreement had been achieved between them. Hence developed model was recommended to be used for predicting flank wear. S. E. Oraby et al. [7], established models for wear, tool life and initial cutting conditions in terms of force ratios by using non-linear regression analysis techniques. For this they conducted turning operations. It had been shown that the thrust component of force, when normalised with respect to the power, or vertical, component of force acting on the tool, provides a sensitive measure of nose, flank and notch wear. A model had been developed describing the initial force ratios as functions of feed component, other cutting parameters had been shown to be secondary importance. Another model had been developed which relates an average measure of wear to cutting parameters, time and thrust force ratio. Third model had been established relating the tool life, to cutting parameters and to initial and final/failure thrust force ratios. After comparison of the predictions of an extended Taylor model and the results of experiments there had been good capabilities of the model. Dragos A. Axinte et al. [8], a method was proposed to allow an experimental determination of the extended Taylor's equation with a limited set of experiments and to provide a basis for the quantification of tool life measurement uncertainty. For finding experimental values for coefficients of the extended Taylor's equation considered was:

$$TL = f(a_p, f, v, VB) = G.a_p^a f^b.v^c.VB^d$$

They conducted experiments in a range of cutting parameters, according to a 2^{3-1} factorial design, machining AISI 316L stainless steel with coated carbide tools using six cutting fluids. The extended Taylor's equation for each fluid was found on the logarithmic scale by linear regression analysis using the least-squares method. As depth of cut was not significant so the extended Taylor's equation was thus simplified as:

$$TL = G^{'}.f^{b^{'}}.v^{c^{'}}.VB^{d^{'}}$$

where G′, b′, c′, d′ simplified extended Taylor's equations coefficients. The ranking of the efficiency of six different cutting fluids was obtained by comparison of tool life.

2.1 Background:

The most widely used tool life equation is the Taylor's equation which relates the tool life T in minutes to the cutting speed in m/min through an empirical tool life constant, C [3]:

$$VT^n = C$$

This equation can be expressed as:

$$V(TL)^n = C, \quad (1)$$

where TL, tool life in minutes.

Taylor's equation reflects the main effect of cutting speed on tool life but does not account for the smaller but significant effects of the feed rate and the depth of cut. Therefore a modified version of Taylor's equation, called the extended Taylor equation used is [3]:

$$V(TL)^n f^a d^b = C_1 \quad (2)$$

where n, a, and b are tool material constants. This equation can be written for tool life as:

$$TL = a_0 \cdot V^{a_1} \cdot f^{a_2} \cdot d^{a_3} \quad (3)$$

where a_0, a_1, a_2 and a_3 are the constants related to tool-work combinations.

There are various methods to determine tool life data. As suggested by Taylor, if wear land is considered to be constant, the wear-land curves can be extrapolated to determine tool life. An equation can be written for tool life in terms of wear [6] as:

$$TL = \frac{w_1 - w}{k_w} \quad (4)$$

where w_1 is wear land failure criterion, w is the wear land intercept found experimentally and k_w is wear land growth rate.

Tool wear, w and cutting time, t mathematically can be expressed [6] as:

$$w = w_0 + m.t \quad (5)$$

where w_0 is initial wear, m is slope of wear- time curve and t is cutting time.

As an increase in wear is dependent on the given cutting conditions [6], tool wear can be expressed as:

$$w = w_0 + a_0 \cdot V^{a1} \cdot f^{a2} \cdot d^{a3} \cdot t^{a4} \quad (6)$$

where a_0, a_1, a_2, a_3, a_4 are constants.

If machining time is maintained constant, then tool wear can be said to be function of process parameters i.e. cutting speed, feed and depth of cut

i.e. w = f (V, f, d)

A mathematical model for tool wear as a function of process parameters was proposed as:

$$w = a_0' V^{a1'} \cdot f^{a2'} \cdot d^{a3'} \quad (7)$$

where w is tool wear, V is cutting speed in m/min, f is feed in mm/rev, d is depth of cut in mm, a_0', a1′, a2′, a3′ are constants, which can be found out experimentally.

3. EXPERIMENT:

For the experimental purpose tool steel Vanadis23 material was procured from Bohler-Uddeholm India Pvt. Ltd. Eight samples (total 24 pieces) of this tool material were used. The chemical composition of material given by source Company was as shown in Table 1.

Table1: Chemical Composition of PM Vanadis23 Tool Steel

C	Si	Mn	P	S	Cr	Mo	W	V
1.30	0.57	0.33	0.022	0.008	4.02	4.85	6.12	3.00

The aim of this research work is to study the performance by correlating the process parameters in turning. From the experimental data obtained it is planned to establish an empirical mathematical model for Vanadis23 PM steel tool and mild steel-Fe410 as work material combination to determine wear at a given cutting speed, feed and depth of cut. As there are three parameters whose effect is to be evaluated on tool wear, it is decided to use Taguchi OA method for conducting the experiments. The purpose of use of Taguchi's OA method is as it provides readily available fractional factorial matrices orthogonal arrays which minimize the number of experiments [9]. Therefore L_8 (2^7) array is planned to be used. As cutting speed has highest effect on tool wear in comparison to feed and to depth of cut, four levels of cutting speed are decided to be used. Hence column no. 1, 2 and 3 merged to have column no.1 and cutting speed is allocated to this column in modified L_8. Feed and depth of cut are used at two levels and allocated to column no. 3 and 4 in the modified L_8 array. In this way modified L_8 array as shown in Table 2 in which one factor at four level and two factors at two levels is finalized for experimentation.

Table 2: Modified L_8 Orthogonal Array (One four- level factor)

Standard column no.					
	123	4	5	6	7
Modified column no.					
Column → Experiment No. ↓	1	2	3	4	5
1	1	1	1	1	1
2	1	1	2	2	2
3	2	2	1	2	1
4	2	2	2	1	2
5	3	1	2	1	2
6	3	1	1	2	1
7	4	2	2	2	2
8	4	2	1	1	1

All samples were subjected to conventional heat treatment in vacuum furnace. The heat treatment process used was as shown Fig.1, in which the material was subjected to austenitizing at temperature of 1040°C and tempered twice at a temperature of 500°C and 530°C respectively.

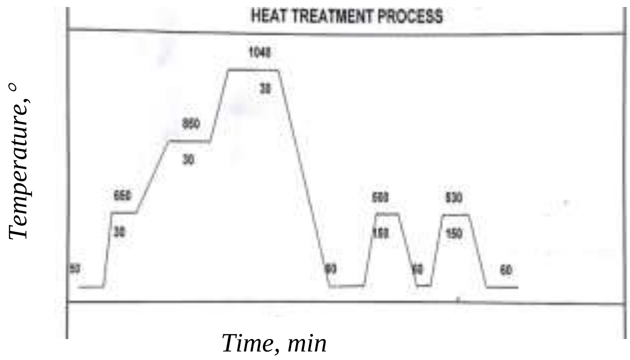

Figure 1: Heat Treatment Process

The samples were then ground to single point tools applying standard tool geometry. The process parameters used in turning operation for these tools with mild steel-410 as work material were as shown in Table 3.

Table 3: Process Parameters and Their Values at Different Levels

Process parameters	Symbol	Level 1	Level 2	Level 3	Level 4
Cutting speed, m/min	V	12	13.8	15.87	18.25
Feed, mm/rev	F	0.1	0.115	---	---
Depth of cut, mm	d	0.5	0.575	---	---

The experiments were performed on the CNC lathe machine- ACE DESIGNERS, APPOLLO. The parameters used as per the modified L_8 array were shown in Table 3. In modified L_8 array experiments were repeated three times maintaining all other factors constant under dry conditions. When turning operation completed, flank wear of the tools was measured by using Mitutoyo tool maker's microscope.

4. ANALYSIS OF DATA:

Table 4 shows the results obtained from the experiments and measurements of flank tool wear. In this Table 4, Y_1, Y_2 and Y_3 indicate the response (flank wear) in the first, second and third replications respectively, average arithmetic values of tool wear and S/N ratio (dB) for the tool wear data are shown.

Table 5 shows the ANOVA and 'F' test values with percentage contribution of each factor. From this it is clearly observed that all three factors i.e. cutting speed, feed and depth of cut have significant effect on the tool wear. For the selected parameters for experimentation, the analysis indicates that depth of cut, feed and cutting speed are in descending order.

Table 4: S/N Analysis for Vanadis23 PM Conventionally Treated Tools Flank Wear

Experi-ment No.	Column No.			Response Tool wear, w mm			Average tool wear, w mm	S/N ratio (dB) for tool wear
	1	2	3	Set I Y_1	Set II Y_2	Set III Y_3		
1	1	1	1	0.05	0.046	0.048	0.048	26.370152
2	1	2	2	0.054	0.05	0.049	0.051	25.840811
3	2	1	2	0.052	0.056	0.048	0.052	25.662835
4	2	2	1	0.057	0.054	0.052	0.054	25.292466
5	3	2	1	0.063	0.062	0.054	0.060	24.465620
6	3	1	2	0.06	0.059	0.062	0.060	24.386998
7	4	2	2	0.073	0.075	0.073	0.074	22.653868
8	4	1	1	0.068	0.069	0.07	0.069	23.222410

Table 5: **ANOVA and 'F' Test for Tools Flank Wear**

Source	SS	DOF	Variance	F ratio	Pure Sum of Squares	% Contribution
A	11.5075	3	3.83582	151.069	11.4313	96.215774
B	0.24138	1	0.24138	9.50658	0.21599	1.817959
C	0.08123	1	0.08123	3.19921	0.05584	0.469998
Error	0.05078	2	0.02539			1.496269
Total		7				100

Figure 2 depicts the graphical representation of the S/N ratio (dB) for different factor levels.

Correlating all three factors, an empirical mathematical model using the results obtained can be developed for tool wear.

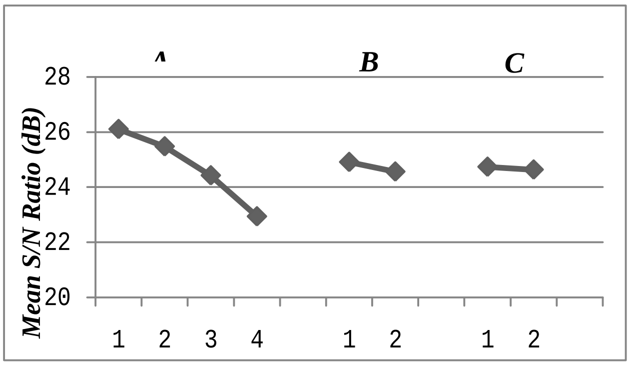

Figure 2: Average S/N Ratio by Factor Level for Tool Wear

A – Cutting speed (m/min), B – feed (mm/rev), C– Depth of cut (mm)

By using non linear regression analysis an empirical mathematical model for finding the effect of process parameters on tool wear (response) of Vanadis23 PM steel tool obtained is given as follows:

$$\ln w = V \ln 1.060673 + f \ln 14.11905 + d \ln 1.364724 + \ln 0.01524 \qquad (8)$$

where w is tool wear in mm, V is cutting speed in m/min, f is feed in mm/rev and d is depth of cut in mm. The coefficient of determination, R^2 for the developed model is 0.981086.

4.1 Confirmation Experiments:

4.1.1 Determination of the Optimum Condition:

The response ratio and S/N ratio can be used to determine the optimum condition, which is essentially the optimum combination of the treatment levels for the given response. As the quality characteristic, wear, w is a smaller-the better characteristic, the smallest response is the ideal level for a parameter. The S/N ratio though will be always be highest at the optimum condition, but it is always desired that the signal to be much higher than the noise. Though not all treatment combinations have been run in the experiment, it requires a separate analysis, which considers all possible treatment combinations. From data obtained in Table 4 the optimum combination is selected and it is therefore A_1, B_1 and C_1 i.e. cutting speed 12 m/min, feed 0.1mm/rev and depth of cut 0.5 mm. This optimum condition has been used in the experimentations.

4.1.2 Predictive Equation and Verification:

To verify the optimum combination it is necessary to use a predictive equation to predict a response value given in the combinations of each factor at its level in the optimum combination. A simple yet effective equation generally used for such type of study is given by Fowlkes and Creveling [10] is as:

$$y_{predicted} = \overline{y}_{\exp} + \left(\overline{y_A} - y_{\exp}\right) + \left(\overline{y_B} - y_{\exp}\right) + \left(\overline{y_C} - y_{\exp}\right) \qquad (9)$$

where $y_{predicted}$ = the predicted response value (in this case wear, w) or S/N ratio; $\overline{y_{\exp}}$ = the overall mean response of the experimental runs (in this case wear, w) or S/N ratio; and $\overline{y_A}$, $\overline{y_B}$, $\overline{y_C}$ = the responses or S/N ratio effects for A, B and C (in this case V, f and d) at a given level for each. Applying this formula to the data in Table 4, predicted response at the ideal condition is 0.047973 mm and predicted S/N ratio is 26.379951.

Next, the robustness of this parameter optimization was checked experimentally. For this three experiments were conducted at both the optimum condition and one of the other experimental combinations. Then tool wear was measured by using the same arrangement. The results obtained for these confirmation runs, including responses are shown in Table 6 (a) and (b), which can be used to interpret robustness of this experiment. The "non optimum" condition was that treatment combination which yielded the highest response in the experimental runs. As observed from Table 6 (b) the error between predicted and confirmation runs results are very low. As well as Table 6 (b) shows the tool wear calculated by using the empirical mathematical model developed for both conditions according to equation no. (8). As the error between actual measured wear and calculated from empirical mathematical model for optimum condition is very less it indicates validity of the developed empirical mathematical model.

Table 6 (a) Results of Confirmation Experiments

Confirmation experiment combination	Chosen parametric values			Experimental results wear (mm)			
	V, m/min	f, mm/rev	d, mm	Expt1	Expt2	Expt3	Average
Optimum	12	0.1	0.5	0.048	0.046	0.047	0.047
Non optimum	18.25	0.115	0.575	0.071	0.073	0.072	0.072

Table 6 (b) Results of Confirmation Experiments

Experimental results		Predicted values		As per developed model		% Error	
Wear (mm)	S/N ratio	Wear (mm)	S/N ratio	Wear (mm)	S/N ratio	Predicted values	As per developed model
0.047	26.556863	0.047973	26.379941	0.04703	26.72409	2.0282	6.3789

5. DISCUSSION:

Three cutting parameters and wear plots are drawn. Figure 3 to 5 show the plots of cutting speed versus tool wear, feed versus tool wear and depth of cut versus tool wear respectively. From the plot of cutting speed and tool wear it is observed that as cutting speed increases the tool wear increases. The way of increase in tool wear is an exponential manner. At extremely slow cutting speeds the heat generated in machining operation is carried away by the chip and work piece, tool and atmosphere. The level of temperature remains low in the area of cutting edge. So it is not harmful in case of machining. The higher the cutting speed the smaller the tool life. Increasing the cutting speed increases cutting temperatures, this leads to increase in wear and plastic deformation of the cutting edge [5]. Many other factors are affecting on tool wear but Taylor related the tool life and cutting speed by an equation [3]

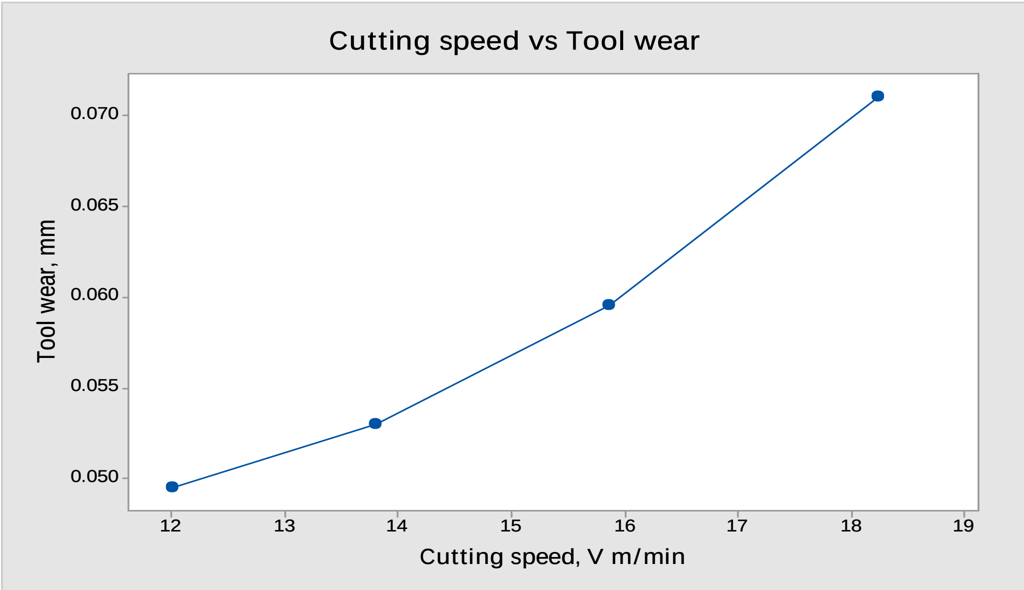

Figure 3: Cutting speed Versus Tool Wear

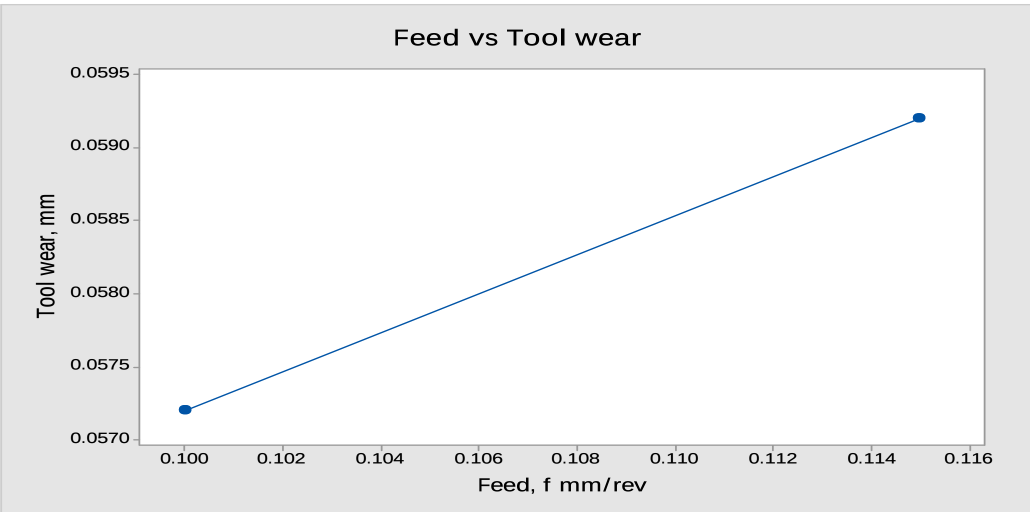

Figure 4: Feed Versus Tool Wear

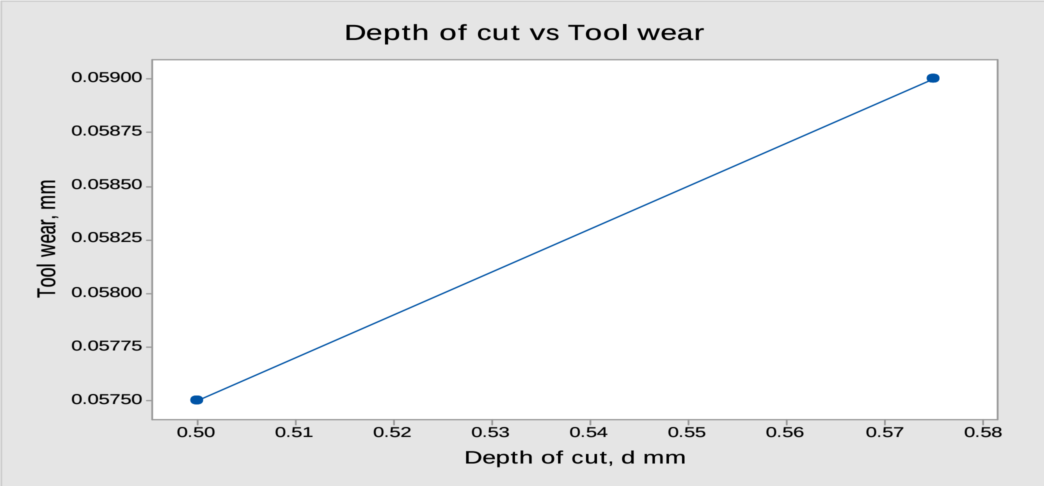

Figure 5: Depth of Cut Versus Tool Wear

Feed rate and depth of cut are the other important variables which also affect the tool life considerably. An increase in feed rate and depth of cut also reduce the tool life [2]. In the present work only two levels of feed and depth of cut are selected. These two factors have small effect on the tool wear in comparison to cutting speed. Figure 4 shows the graph of feed versus tool wear. The graph indicates that for the present tool material tool wear increases as feed rate increases. Figure 5 shows the graph of depth of cut versus tool wear. From the graph it is seen that as depth of cut increases the tool wear increases.

In this research work Vanadis23 PM steel tool has been used to establish an empirical mathematical model for evaluating the tool wear during turning operation. Taguchi's L_8 modified orthogonal array is being used to decide the number of experiments. The developed model can be proposed to predict tool wear of a tool under different combinations of cutting speed, feed and depth of cut during turning operation. The coefficient of determination, R^2 for the developed model is 0.981086, which shows a very good validity of the developed model.

6. CONCLUSIONS:

In this research paper Vanadis23 PM steel tool has been used to establish an empirical mathematical model for evaluating the tool wear during turning operation. Taguchi's L_8 modified orthogonal array is being used to decide the number of experiments. The developed model can be proposed to predict tool wear of a tool under different combinations of cutting speed, feed and depth of cut during turning operation. The coefficient of determination, R^2 for the developed model is 0.981086, which shows a very good validity of the developed model.

The results obtained from the experimentation are confirmed by conducting optimum and one of the non optimum conditions. The results obtained from experiments, prediction and developed model are in good agreement.

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