Investigations on wear resistance of PM steel tool after heat treatment

D. M. Dalwe[#1] R.G. Tated[*2]

[#]Asst. Prof. in Mechanical Engineering Department, S. T. B. College of Engineering, Tuljapur, Dist. Osmanabad.
[*]Prof. in Mechanical Engineering Department, Matoshree College of Engineering, Nashik.
[1] Email: dalwedm2007@gmail.com
[2] Emial: rgtated@yahoo.com

***Abstract* -The powder metallurgy tool steel Vanadis23 PM is studied in this research work. The tool material was conventionally heat treated. The effect of heat treatment on wear is evaluated by using a single point cutting tool in turning operation under dry condition. For wear analysis under different turning parameters, regression and ANOVA analysis have been carried out. The comparison of tool wear obtained is done by using experimental, predicted and regression model.**

***Keywords*- PM steel tools, heat treatment, Taguchi method, wear resistance, hardness.**

I. INTRODUCTION

The definition of heat treatment given in the metal Handbook is: “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.” All basic heat treatment processes for steel which result in the transformation or decomposition of austenite. The physical and mechanical properties of any steel are based on the nature and appearance of transformation products. The initial stage in the heat treatment of steel is to heat the material to some temperature in or above the critical range so that austenite is formed. In most of cases, the rate of heating to the desired temperature is not so important compared to other factors on the heat treating cycle. The different heat treatment processes to obtain desired requirements used in practice are full annealing, spherodizing, stress-relief annealing, process annealing, normalizing, etc. Sometimes other processes like hardening and tempering etc. are also used [1,2].

The powder metallurgy tool steel Vanadis23 is studied in this work. 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 [3].

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].

Baykara T and Bedir HF [5], the Vanadis4 extra samples were annealed at 1000°C for 9 minutes and Vanadis10 at 800°C for 5 minutes and quenched into water at room temperature. There was distinct increase in micro hardness values and considerable increase in wear resistance would be the results of microstructural formation. Substantial increase in wear resistance of the heat treated Vanadis10 would be due to grain growth of carbide grains embedded in the ferrite matrix. Larger size carbide grains might be played inhibiting role against the wear mechanism in between the surfaces of Vanadis10 samples and AISI H13 steel disc.

Noor Mazni Ismail et al. [6], the annealed specimen with mainly ferrite structure gave the lowest hardness value but highest ductility and toughness value. The quenching increased the hardness and specimen was become too brittle and not suitable for any application. The hardness value after quenching in water was 11.85 HRC and cooling by open air was 8.95 HRC. The hardness after tempering was decreased when tempering temperature increased. The toughness of steel increased as the absorbed energy increased when tempering temperature increased. The microstructure obtained after tempering provided a good combination of mechanical properties as it reduced brittleness by increased ductility and toughness and at the same time reduced hardness when temperature increased,

Peter Jurci [7] studied the effect of various heat treatments on Cr- and Cr-V ledeburitic steels. The higher austenitizing temperature the lower was the toughness and the fracture toughness. The effect of tempering had a positive effect on these characteristics, excepting the tempering temperatures range typical for secondary hardening peak, where slight decrease of toughness occurred.

Stoicanesceu, et al. [8], the high content of residual austentite found after hardening in 1.3343 (Rp5) high speed steel. The tempering applied shortly after hardening had a sensitive effect upon a residual austentite transformation. The major quantity of transformed structure occurred after first tempering along in the process. On subsequent tempering, gradually the percentage of transformed residual austentite was decreasing. The residual austentite transformation was accompanied by the hardness increasing, more visible after the first tempering and relatively insignificant following the process.

Alias Mohd, et al. [9], the tool steel XW- 42 was the better and harder than the XW-5. XW-5 was suggested for applications demanding maximum wear resistance such as blanking and shearing tools for thin, hard material, long-run press tool and forming tools since of suitable hardness. The XW-42 was a versatile tool steel which can be used for a wide variety of cold work applications like blanking and other cutting processes and several forming processes.

Palash Biswas et al. [10], tempering of EN 8 Steel was done after each heat treatment leads to a decrease in hardness. This was actually desirable, as low hardness and good toughness will be beneficial for machining purposes, because cutting forces and specific energy required will be less. But sometimes, reduced hardness leads to accelerated wear, in some applications and it is not desired. So EN 8 steel should be tempered after normalizing. The microstructure consisted of finer grains and hardness decreased, but not notable, which ensures good machinability.

Bhupinder Singh et al. [11], the normalized specimen of EN-31 showed more hardness. Specimen treated with hardening and tempering was hardest. Specimen of EN-8 became softer than untreated specimen after annealing and normalizing resulted in more hardness. In case of D-3 steel annealing resulted in more hardness. The hardening and tempering made it hardest and gave good corrosion resistance.

Rahul George et al. [12], for EN19 steel the brine quenched specimen shown the highest tensile strength and the annealed one the lowest. The tensile strength of oil, water and brine tempered, specimen decreased by 27.19%, 27.02% and 24.31% respectively. The brine quenched specimen had the highest hardness and the annealed specimen the lowest. The decrease in hardness of oil, water and brine tempered specimen seen was 35.27%, 35.33 and 21.96% respectively. The highest impact strength was in the annealed specimen and the lowest in the brine quenched specimen. The impact strength of oil, water and brine tempered specimens shown increase by 20%, 44.4% and 42.85% compared to oil, water and the brine quenched specimens respectively.

II. EXPERIMENTAL MATERIAL AND TREATMENT

For the experimental purpose tool steel Vanadis23 PM 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 as given by source Company is shown in Table I.

TABLE I
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

Vanadis23 PM steel tool and mild steel-Fe410 as work material combination was used to determine wear at a given cutting speed, feed and depth of cut. Taguchi OA method is used for conducting the experiments to minimize the number of experiments to be performed. Therefore L_8 (2^7) modified array was 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 were decided to be used. For feed, two levels and for depth of cut also two levels were finalized.

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.

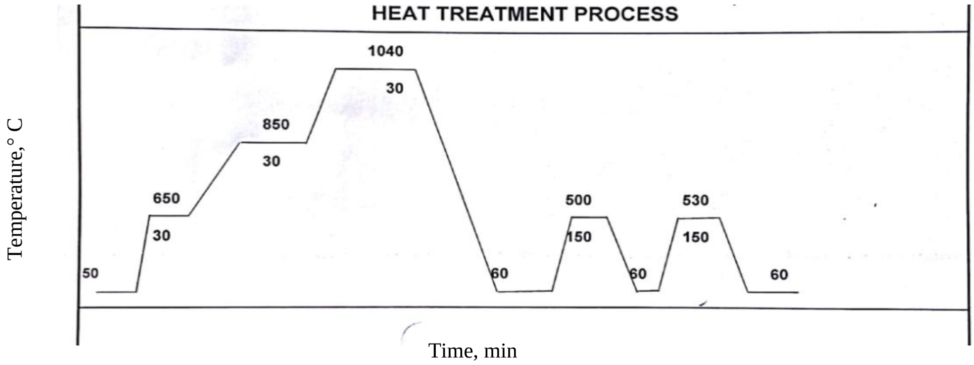

Figure 1: Heat Treatment Process

The samples were then ground to single point tools applying standard tool geometry.

The experiments were performed on the CNC lathe machine- ACE DESIGNERS, APPOLLO. 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. The results are as shown in Table II.

TABLE II
RESULTS OF EXPERIMENTATIONS

Experiment No.	**Results Tool Wear, w mm**			**Average Tool Wear, mm**
	Set I Y_1	**Set I Y_2**	**Set I Y_3**	
1	0.05	0.046	0.048	0.048
2	0.054	0.05	0.049	0.051
3	0.052	0.056	0.048	0.052
4	0.057	0.054	0.052	0.054
5	0.063	0.062	0.054	0.059
6	0.06	0.059	0.062	0.060
7	0.073	0.075	0.073	0.073
8	0.068	0.069	0.07	0.069

III. DISCUSSIONS

The S/N ratio values for all experiments are calculated by using formula,
$S/N = -10 \log_{10} (MSD)$ for smaller is better characteristic,
where MSD is Mean Squared Deviation and $MSD = (Y_1^2 + Y_2^2 + \ldots) / N$
Y_1, Y_2, … etc., are response values and N = number of responses.

TABLE III
S/N ANALYSIS FOR VANADIS23 PM CONVENTIONALLY TREATED TOOLS FLANK WEAR

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

TABLE IV
ANOVA TABLE FOR VANADIS23 PM CONVENTIONALLY TREATED 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

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

By using Taguchi method, followed by ANOVA calculations, it is found that the tool wear is different under employed conditions. The effect of various employed parameters on the tool wear is tabulated as shown in Table III. Table IV gives the ANOVA and 'F' test values with percentage contribution of each factor. From this it is clearly observed that the cutting speed has major effect on the tool wear. For the selected parameters for experimentations, the analysis shows that cutting speed, feed, and depth of cut are in descending order.

The main effects plots for S/N ratios is plotted for smaller the better characteristic. Figure 2 shows the main effects plot of S/N ratios for average tool wear. From this plot it can be seen that cutting speed, feed and depth of cut have first, second and third level significant effect on the tool wear.

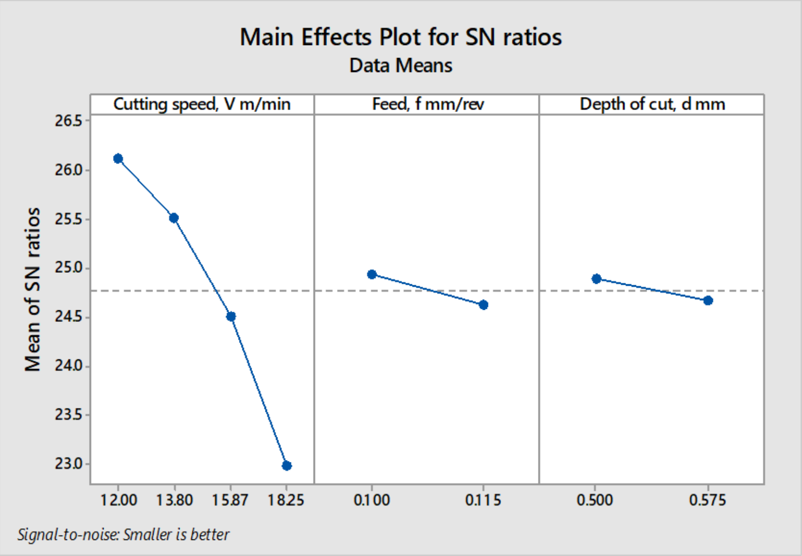

Figure 2 Main Effects Plot for S/N Ratios of Conventionally Treated Vanadis23 PM Tools

Confirmatory tests are conducted for conventionally treated tools. For optimum and non optimum conditions the process parameters found are V = 12 m/s, f= 0.1 rev/min and d = 0.5 mm and V = 18.25 m/s, f= 0.115 rev/min and d = 0.575 mm respectively. The experimental average tool wear for these two conditions are 0.047 mm and 0.072 mm respectively.

A simple yet effective equation generally used for calculating wear (response) is given by Fowlkes and Creveling,

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

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 3, predicted response at the ideal condition wear is 0.047973 mm

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

$$\ln w = V \ln 1.06073 + f \ln 14.11905 + d \ln 1.364724 + \ln 0.01524$$

Tool wear is also calculated by using this equation.

From the confirmation experiment combination the values of tool wear obtained by experiment, prediction and developed empirical model for optimum condition are: 0.047 mm, 0.047973 mm and 0.04703 mm respectively and for non optimum condition 0.072 mm, 0.073589 mm and 0.05442 mm respectively.

The error between actual measured wear and calculated from empirical mathematical model is only 0.06378% for optimum condition of confirmation experiments and 24.55555% for non optimum condition experiments. For optimum condition it indicates a good validity of the empirical mathematical model developed for conventionally treated tools.

Figure 3 shows the comparison of the experimental tool wear, predicted tool wear and wear evaluated from the empirical mathematical model for conventionally treated tools.

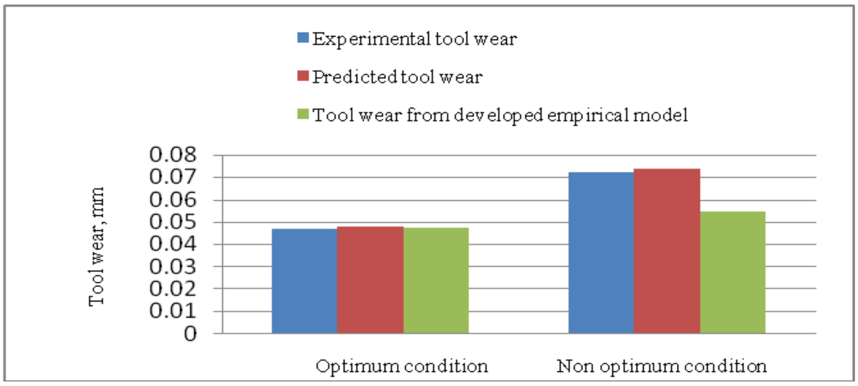

Figure 3 Comparison of Tool Wear for Conventionally Treated Tools

From Figure 3 it can be seen that for optimum condition experimental wear is least and for non optimum condition wear by developed model is least.

IV. CONCLUSIONS

The following conclusions can be drawn:

For the selected parameters for experimentations, the wear analysis shows that the effect of cutting speed, feed, and depth of cut are in descending order. The main effects plot of S/N ratio also indicates same order of turning parameters. The least wear (0.048 mm) is observed for turning parameters: cutting speed 12 m/min, feed 0.1 mm/rev and depth of cut 0.5 mm and it is maximum (0.069 mm) for cutting speed 18.25 m/min, feed 0.115 mm/rev and depth of cut 0.575 mm. For optimum condition a good validity of the empirical mathematical model developed for conventionally treated tools is observed.

From the comparison of experimental, predicted and empirical model it is seen that experimental tool wear is less in optimum condition while tool wear obtained by developed model is least in non optimum condition.

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