

Tool Wear Study on Tin Coated Cutting Inserts During CNC Turning Process

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ABSTRACT: The present research paper is focused on the analysis of optimum cutting conditions to get lowest tool wear rate and tool flank wear in CNC turning of different grades of EN materials by Taguchi approach. The experimentation plan is designed using Taguchi's L₂₇ Orthogonal Arrays (OA). The experimental result analysis showed that the optimum combination of various input factors as type of insert type, work piece material, spindle speed, feed and depth of cut. Analysis of variance (ANOVA) is used to analyse the influence of process parameters during machining. Further, the confirmation tests are conducted and the results are found to be within the confidence interval. In addition, SEM analysis is carried out to study the wear of tin coated cutting tools under varying process parameters.

KEYWORDS: Turning, Tool Wear Rate, Flank Wear, Design of Experiments. CVD Coating, PVD Coating, Optimization.

I. INTRODUCTION

Industries around the world continually strive for lower cost solutions with reduced lead time in order to maintain their competitiveness. It has long been recognized that conditions during cutting, such as feed rate, cutting speed and depth of cut, should be selected to optimize the economics of machining operations as assessed by productivity, total manufacturing cost per component or some other suitable criterion [1]. Regarding economic aspects, tool wear is the most important consideration in the cutting practice. Consequently tool wear prediction and tool substitution policy are regarded as important tasks in order to maximize tool performance and minimize cutting costs. The primary tool wear are classified as flank wear, crater wear and nose wear, are important wear which will affect the smoothness of the product, cost of operation and performance. During turning tool wear is caused by the normal load generated by interaction between tool work piece and tip [2]. Tool wear depends on the tool, work piece material (physical, mechanical and chemical properties), tool geometry, cutting parameters, cutting fluid, etc. The geometry of the tool plays a big part in controlling wear. The geometry of the cutting tool must allow for chip removal in order to take the heat out with the chip [3]. This study intend to investigate the effect of insert geometries on cutting performance in terms of tool wear when machining of different grades of EN materials.

In manufacturing industries, Dimensional accuracy is a major concern in machining processes. It has been recognized that dimensional accuracy is significantly affected by tool wear [4]. Hence, there is need for a systematic methodological approach by using experimental methods and statistical/mathematical models. The design of experiments (DOE) is a statistical-based approach to analyse the influence of known process variables over unknown process variables [5]. Further the data can be analysed to obtain valid and objective conclusions. Many researchers developed many mathematical models to optimize the cutting parameters to get the lowest tool wear and tool wear rate by turning process. The variation in the material hardness, alloying elements present in the work piece material and other factors affecting tool wear and tool wear rate.

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II. MATERIALS AND METHODS

A. Machine Tool

CNC turning centre (Sprint 16 TC), Batliboi Ltd. is used to carry out the experiment with 7.5 kW(10 hp) spindle power, maximum spindle speed of 5000 rpm, feed range 0-5000 mm/min, Z axis stroke 325 mm and X axis stroke 125 mm. The CNC Machine used in experiments as shown in Figure1.



Figure 1. Experimental Setup

B. Process parameters for experiments with their Levels

Process parameters (control factors) are one of the most important factors for any experimental work. The process parameters in present case are selected based on various literature reviews. Then various cutting parameters are set based on selected inserts. The different levels for process parameters are shown in table 3 below.

Table 3 Levels for Process parameters

Level	Factors				
	A	B	C	D	E
	Insert	Work piece material	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	CN1500	EN-8	100	0.15	0.5
2	CN8020	EN-31	125	0.2	1
3	CC1500	EN-36	150	0.25	1.5

III. EXPERIMENTAL PLAN AND PROCEDURE

Turning experiments are carried out on a CNC turning centre under dry cutting conditions. Lubrication is normally used in machining to prevent cutting at excessive high temperature. Basically, lower cutting temperature results in longer tool life of the cutting tool. But in the case of cutting tool inserts with TiN coating, the cutting tool insert will work better at high temperature. Dry cutting is better than wet cutting for TiN coating inserts under high speed cutting [6].

A. Response Characteristic

In present study parameters taken as a response are tool wear rate and flank wear.

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a) Tool Wear Rate

As the tool material used for the experimentation possesses different values of densities, the tool wear rate in terms of ‘change in volume’ per unit time can be a better measure of the rate at which the different tools materials are eroded while machining takes place. Hence, the tool wear rate is calculated [10] as reduction in volume per unit time (mm^3/min) so as to facilitate more accurate comparison of the TWR for different tool materials under varying process conditions.

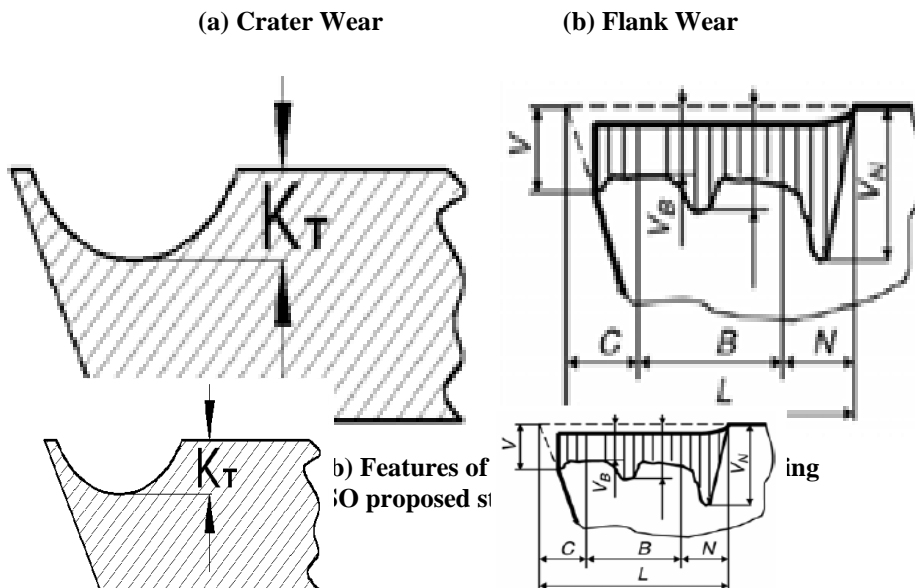
$$TWR = \frac{W_i - W_f}{(t_m)(\rho)} \quad \text{----- (1)}$$

Where, W_i = Initial Weight of cutting insert in gm.
 W_f = Final Weight of cutting insert in gm.
 t_m = Machining time in minute.
 ρ = Density of the Tool material in gm/cm^3 .

Here density for K20 and P30 cutting tool materials are $14.8 \text{ gm}/\text{cm}^3$ and $11.4 \text{ gm}/\text{cm}^3$ respectively [11].

b) Study of different modes of wear

Flank and crater wear are the most important measured forms of tool wear. The flank wear in these experiments can be seen obviously when high speed turning applied. Generally speaking, flank wear is caused by friction between the flank face of the tool and the machined surfaces. Flank wear is generally attributed to rubbing of the tool with work piece at the interface, causing abrasive and/or adhesive wear at high temperatures. Abrasion is the main wear mechanism in flank wear [12]. Researchers normally regard flank wear land width V_B as the tool life criterion owing to its significant influence on surface finish and dimensional accuracy of the machined part [13-14]. Crater wear occurs on the rake face of the tool. The crater wear affects the tool geometry. The most important factors influencing crater wear is temperature at the tool tip interface and the chemical affinity between tool and work piece materials. During machining, flow of chips on the rake face result in severe friction and thus leads to material removal, referred as crater wear. The abrasion is a mechanically activated form of wear, which depends upon on the material properties like hardness, carbides, marten site structure, etc. [12]. BUE and irregular wear are often faced in machining stainless steels. At low cutting speed, the contact between work piece and flank of the tool was more and rubbing action continued for more time. The cutting zone temperature increases, this softens and decreases the strength of the BUE [15].



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Figure 3.Loading and Magnification of the insert by use of S-3400N Scanning Electron Microscope

As part of present study, Depth of flank wear V_B has been measured using Scanning Electron Microscope S-3400N. Flank wear is characterized by the average width V_B . Tool damage on the rake face is characterized by the maximum depth K_T of the crater shown in figure 2 (a) and (b). Further, the wear trends for different combination of input parameters in SEM are observed and discussed.

IV. EXPERIMENTAL DESIGN

The objective of Design of experiment is to determine the variables in a process that are the critical parameters and their target values. On the basis of selected parameters, experimental design is carried out.

Table 4. Experimental results for L27 OA

Sr. No	Insert Type	W/P Mat.	Cutting Speed 'Vc' (m/min)	Feed 'f' (mm/rev)	D.O.C. 'dc' (mm)	TWR (mm ³ /min)			Flank Wear (μm)		
						Set 1	Set 2	S/N Ratio	Set 1	Set 2	S/N Ratio
1	CN 1500	EN-8	100	0.15	0.5	12.2593	12.2517	-21.7666	96	91.8	-39.4555
2	CN 1500	EN-8	100	0.15	1	11.8965	11.7864	-21.4682	137	263	-46.4315
3	CN 1500	EN-8	100	0.15	1.5	11.079	10.8212	-20.789	110	116	-41.0646
4	CN 1500	EN-31	125	0.2	0.5	11.8243	11.9642	-21.5069	138	118	-42.1706
5	CN 1500	EN-31	125	0.2	1	11.3692	11.2613	-21.0733	113.7	126	-41.5842
6	CN 1500	EN-31	125	0.2	1.5	11.2943	11.2678	-21.047	94.9	102	-39.87
7	CN 1500	EN-36	150	0.25	0.5	13.2187	13.172	-22.4084	116	120	-41.4389
8	CN 1500	EN-36	150	0.25	1	12.7887	13.0174	-22.2142	156	185	-44.6658
9	CN 1500	EN-36	150	0.25	1.5	12.7348	12.6233	-22.0618	140	162	-43.6025
10	CN 8020	EN-8	125	0.25	0.5	4.2805	4.2347	-12.5834	61.9	64.9	-36.0442
11	CN 8020	EN-8	125	0.25	1	4.2833	4.284	-12.6362	42.1	35.5	-31.8079
12	CN 8020	EN-8	125	0.25	1.5	4.2183	4.1758	-12.459	70.5	71.6	-37.0315
13	CN 8020	EN-31	150	0.15	0.5	5.2074	5.0655	-14.214	55.6	52.8	-34.6829
14	CN 8020	EN-31	150	0.15	1	5.1268	5.1195	-14.1907	42.2	20.9	-30.4486
15	CN 8020	EN-31	150	0.15	1.5	5.2056	5.086	-14.2297	50	49.4	-33.9273
16	CN 8020	EN-36	100	0.2	0.5	4.1201	4.0527	-12.2271	41.8	44.5	-32.7039
17	CN 8020	EN-36	100	0.2	1	4.143	4.1444	-12.3478	55.3	53.8	-34.7367
18	CN 8020	EN-36	100	0.2	1.5	4.0903	4.1164	-12.2628	60.9	60.2	-35.6424

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19	CC 1500	EN-8	150	0.2	0.5	6.6602	6.8289	-16.5798	71.4	77	-37.4143
20	CC 1500	EN-8	150	0.2	1	7.4668	7.3028	-17.3673	97.9	125	-41.0053
21	CC 1500	EN-8	150	0.2	1.5	7.7188	7.8717	-17.837	118	130	-41.8786
22	CC 1500	EN-31	100	0.25	0.5	7.0356	6.951	-16.8938	79.4	84.6	-38.2806
23	CC 1500	EN-31	100	0.25	1	7.5308	7.8059	-17.6954	95.3	104	-39.9778
24	CC 1500	EN-31	100	0.25	1.5	7.8427	7.9301	-17.9377	120	129	-41.9091
25	CC 1500	EN-36	125	0.15	0.5	5.3209	5.4096	-14.5921	109	137	-41.854
26	CC 1500	EN-36	125	0.15	1	5.6605	5.7772	-15.1467	131	144	-42.7757
27	CC 1500	EN-36	125	0.15	1.5	5.9584	6.0211	-15.5483	182	223	-46.1728

The Taguchi experimental design is done for L₂₇ OA for five parameters which are insert, material, speed, feed and depth of cut. Table 4 shows complete design matrix with coded variables as well as actual value of this variable.

V. EXPERIMENTAL RESULTS & DISCUSSION

MINITAB statistical software has been used for the analysis of the experimental work. The MINITAB software studies the experimental data and then provides the calculated results of signal-to-noise ratio. In this work, the software has given the signal-to-noise ratio for both the tool wear rate and flank wear. The effect of different process parameters on tool wear rate and flank wear are calculated and plotted as the process parameters changes from one level to another. The average value of S/N ratios has been calculated to find out the effects of different parameters and as well as their levels. The use of both ANOVA (Analysis Of Variance) technique and S/N ratio approach makes it easy to analyse the results and hence, make it fast to reach on the conclusion [17]. In turning operation, desired responses are minimum tool wear rate and minimum flank wear so, smaller the better “SB” ratio were selected. The S/N ratio for minimum responses type of characteristic can be calculated as follows [18].

$$\eta = -10 \log \left[\frac{\sum_{n=1}^{N_i} \frac{y_u^2}{N_i}}{N_i} \right] \text{-----(2)}$$

Where y₁, y₂, ..., y_n are the responses of the machining characteristics for a trial condition repeated for n times.

A. Tool Wear Rate

Figure 4. Shows the response diagram for tool wear rate. Tool wear rate is being smaller the better characteristics. From the response diagram it can be seen that an optimum combination of parameters is A2-B3-C2-D1-E1. It means that EN 36 gives minimum tool wear rate when machined by CN8020 tool at 125 m/min speed, 0.15 mm/rev feed and 0.5 mm depth of cut. It can be seen that PVD coated inserts are better for less tool wear rate and geometry point of view positive inserts are superior as compare to negative inserts for less TW. The tool wear rate greatly increases as the feed is increased. In case of cutting speed, it is clear that tool wear rate would less for medium and low speed. As speed is increased, tool wear rate would increase and tool wear rate is constant for different depth of cut. Also the graph shows that for minimum tool wear rate EN-36 material is preferable as compare to EN-8 and EN-31.

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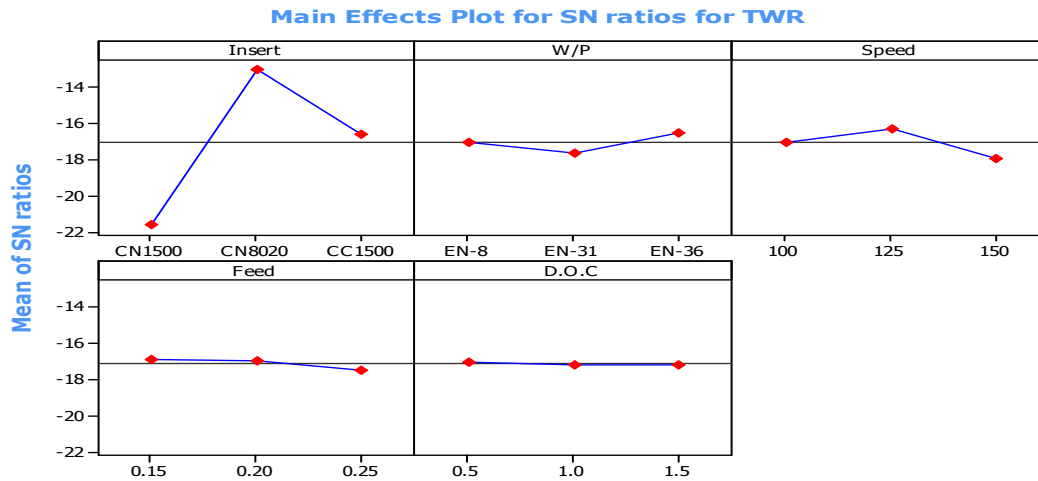


Figure 4. Response Diagram for Tool Wear Rate

Table 5 shows that ANOVA for tool wear analysis it can be seen that insert is most significant parameter affecting tool wear rate with 94.58% significance. The significance of speed, depth of cut, feed and w/p material are found to be 3.32%, 0.04%, 0.48 and 1.57% respectively.

Table 5 ANOVA for tool wear rate analysis

Factors	SS	DF	MS	F	%P
Insert	185.426	2	92.713	2352.039	94.58
w/p material	3.0777	2	1.539	39.039	1.57
Speed	6.507	2	3.253	82.536	3.32
Feed	0.948	2	0.474	12.027	0.48
D.O.C	0.0788	2	0.039	1	0.04
Total	196.037	10	98.01874	2486.642	100

B. Confirmation Tests for TWR

The confirmation experiment is the final step in verifying the conclusions drawn based on Taguchi's parameter design approach. The confirmation experiment is very important in parameter design, particularly when screening or small fractional factorial experiments are utilized [19].

Table 6 Confirmation test for TWR

Response	Optimum combinations for confirmations test	Set 1	Set 2	S/N Ratio for confirmations test combinations	S/N Ratio for experimental combinations
TWR (mm ³ /min)	A2-B3-C2-D1-E1	4.157	4.012	-12.224	-13.017

In this study, a confirmation experiment for dry machining is conducted by utilizing the level of optimal process parameters (A2-B3-C2-D1-E1) for minimum tool wear rate. The purpose of the confirmation experiment in this study was to validate the optimum cutting conditions (A2-B3-C2-D1-E1) that were suggested by the experiment and

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corresponded with the predicted values of average tool wear rate. The confirmation runs with optimum tool wear rate parameters (A2-B3-C2-D1-E1) resulted in tool wear rate values of 4.157 mm³/min and 4.012 mm³/min. Each tool wear rate measurement was repeated and S/N ratio for optimum tool wear rate (-12.224) has been obtained.

C. Flank Wear

Flank wear is being smaller the better characteristics. From the response diagram in figure 5 it can be seen that an optimum combination of parameters is A2-B2-C3-D2-E1. It means that EN 31 gives minimum flank wear when machined by CN8020 tool at 150 m/min speed, 0.20 mm/rev feed and 0.5 mm depth of cut. It can be seen that PVD coated inserts are better than CVD coated inserts for decrease in flank wear and for less flank wear of inserts, EN-31 materials are most preferable. In case of cutting speed, if cutting speed is low then flank wear would decrease and vice versa but after certain stages for the high value of speed again flank wear would decrease. Also the graph shows that at low value of feed, flank wear would decrease and when feed is increase flank wear would increase but again if feed is increased then flank wear would increase. For depth of cut, it can be seen that if depth of cut is increased then flank wear would increase.

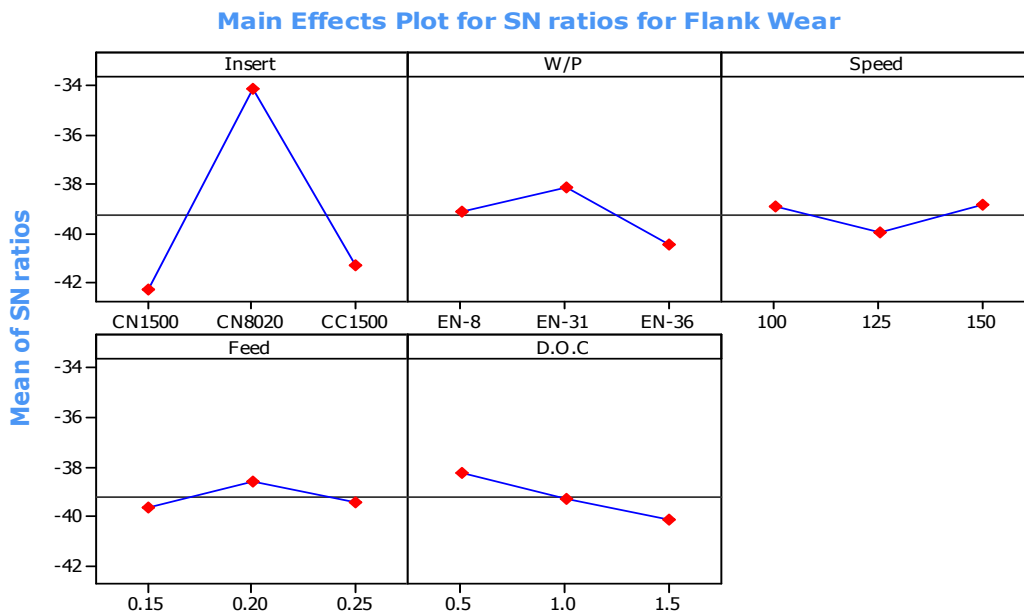


Figure 5. Response Diagram for Flank Wear

Table 7 ANOVA for flank wear analysis

Factors	SS	DF	MS	F	%P
Insert	197.019	2	98.510	59.659	86.96
W/p mat.	13.327	2	6.664	4.036	5.88
Speed	3.894	2	1.947	1.179	1.72
Feed	3.302	2	1.651	1	1.46
D.O.C	9.007	2	4.504	2.727	3.98
Total	226.55	10	113.275	68.601	100

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Table 7 shows that ANOVA for flank wear analysis it can be seen that insert is most significant parameter affecting flank wear with 86.96% significance. The significance of speed, feed, depth of cut, w/p material is found to be 1.72%, 1.46%, 3.98% and 5.88% respectively.

D. Confirmation Tests For Flank Wear

The confirmation runs with optimum flank wear parameters (A2-B2-C3-D2-E1) resulted in flank wear values of 40.8µm and 41.2µm. Each flank wear measurement was repeated and s/n ratio for optimum flank wear (-32.255) has been obtained.

Table 8 Confirmation Test for Flank Wear

Response	Optimum combinations for confirmations test	Set 1	Set 2	S/N Ratio for confirmations test combinations	S/N Ratio for experimental combinations
Flank wear(µm)	A2-B2-C3-D2-E1	40.8	41.2	-32.255	-34.114

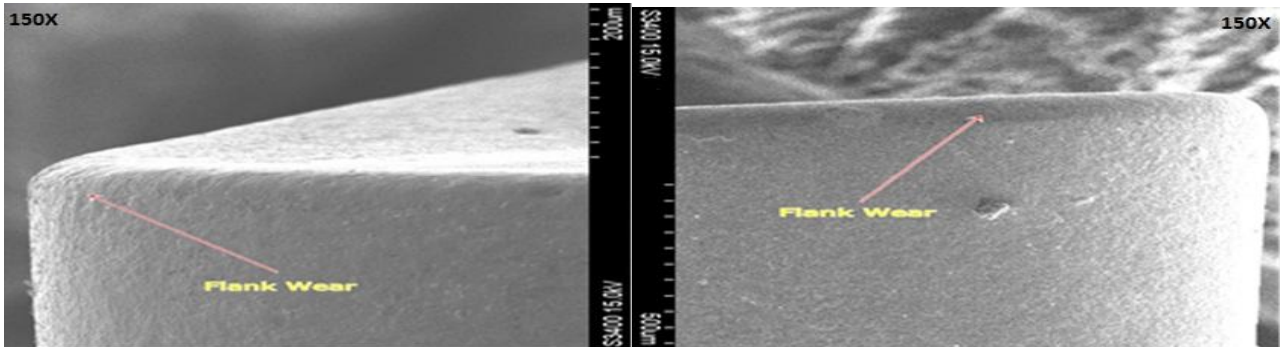


Figure 6. SEM Photographs for flank wear during confirmation test

It can be seen that, the values of S/N ratios for all optimum combinations are higher as compare to experimental combinations of parameters. Hence, the experimental plan and conclusion are verified and acceptable. The above two SEM photographs shown in figure 6 shows the minimum flank wear for the optimum confirmation test. The minimum flank wear was found during the test and the measured data for flank wear given in Table no. 8.

E. Tool wear conditions

Wear occurred freshly when high speed turning applied in cutting speed. This is due to high temperature generated in high speed turning. The experiments with different operating parameters using CNMG 1500, CNMG 8020 and CCMT 1500 tools on EN materials where investigated and the findings are given in following.

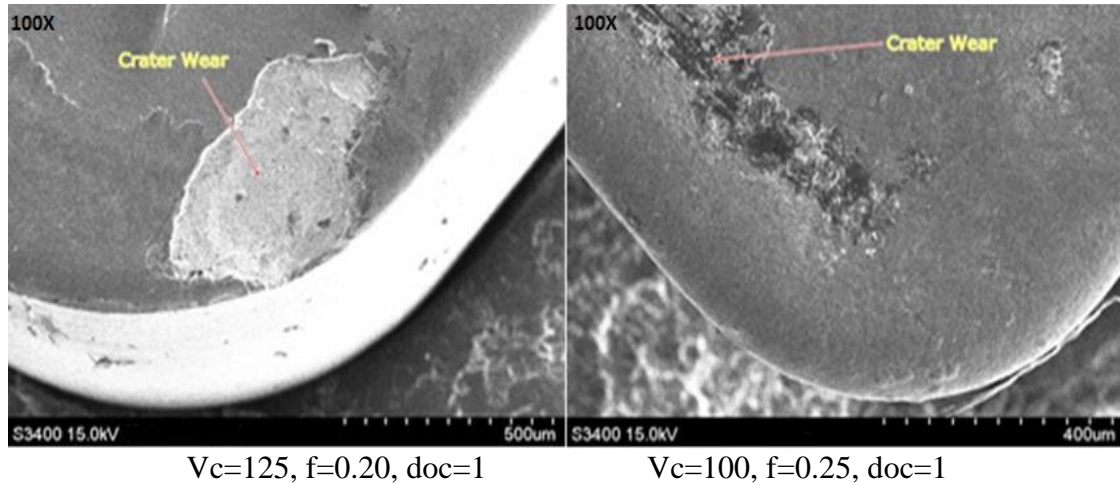


Figure 7. Crater wear formation for EN-31 under 100X magnification

The crater wear is found in this experiment run when machining at 125 m/min cutting speed, 0.20 mm/rev feed, DOC 1mm for material EN 31 and insert CNMG 1500. Also the crater wear in this experiment is found when machining at 100 m/min cutting speed, 0.25 mm/rev feed, DOC 1mm for material EN 31 and insert CCMT 1500. Here, one remark is that the crater wear was not present at higher cutting speed.

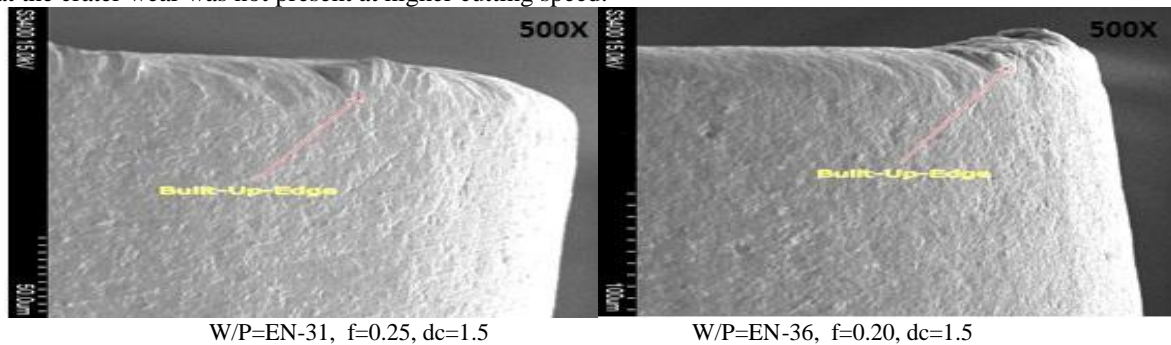


Figure 8. Built Up edge formation at cutting speed of 100 m/min

The BUE is formed at 100 m/min cutting speed, 0.25 mm/rev feed, DOC 1.5 mm for material EN 31 and insert CCMT 1500 and also one remark is that the flank wear was not present in this combination of parameters. The BUE is also formed at 100 m/min cutting speed, 0.20 mm/rev feed, DOC 0.5mm and at 100 m/min cutting speed, 0.20 mm/rev feed, DOC 1.5mm for material EN 36 and insert CNMG 8020. here also the flank wear was not present.

VI. CONCLUSION

Turning tests were performed on three different types of materials viz; EN-8, EN-31, EN-36 and three different types of TiN coated carbides cutting inserts CNMG 1500, CNMG 8020, CCMT1500 are experimentally investigated on CNC turning centre. It can be concluded from the results that for particular material and inserts different parameters make different relations with responses. Observing the wear trends in SEM, based on the SEM micrographs following conclusions have been observed:

1) Maximum flank wear 263 µm observed on CNMG 1500 insert at speed 100 m/min, feed 0.15 mm/rev and 1 mm depth of cut and also from results PVD coated inserts are better than CVD coated inserts for less flank wear.

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- 2) Maximum tool wear rate $13.21 \text{ mm}^3/\text{min}$ observed on CNMG 1500 insert at speed 150 m/min, feed 0.25 mm/rev and 0.5 mm depth of cut and also from results PVD coated inserts are better than CVD coated inserts for less tool wear rate.
- 3) Negative type insert is better than positive type inserts for minimum tool wear rate.
- 4) Analysis of variance suggested the Cutting inserts has a most significant impact on flank wear and tool wear rate.
- 5) Crater wear is not found at higher cutting speed.
- 6) At low cutting speed of 100 m/min formation of built up edge is inevitable due to more contact time.

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