IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 3, June-July, 2015
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Wear Analysis Of Single Point Cutting Tool With And Without Coating

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Abstract

The machining of hardened steel with advanced cutting tool has several advantages over conventional method such as short cycle time, process flexibility, compatible surface roughness, higher material removal rate and less environment problems with absence of cutting fluid. However, caused severe tool wear and changes to quality and performance of product due to higher mechanical stress and heat generation. Thus, proper criteria should be adopted to keep the longer tool life and maintaining the quality of surface integrity. In the present work, Design of Experiment (DOE) with Taguchi L9 Orthogonal Array (OA) has been explored to produce 9 conditions for turning operation and studied the performance of multilayer coated (Al_2O_3+TiC+TiN+AlCrN) ceramic tool in machining of hardened AISI 4340 steel (46 HRC) under dry machining and compared with that of uncoated ceramic tool on CNC machine. The cutting variables were cutting speed (125-175 m/min), depth of cut (0.25-0.63 mm) and feed rate (0.10-0.25 mm/rev).The highest tool wear for multilayer coated and uncoated ceramic tools were 0.364 and 0.639 mm which associate to cutting speed of 175 m/min and depth of cut of 0.63 mm. The surface roughness, Ra values attained throughout the experiments were in range of 0.22 to 4.00 µm which is acceptable according to ISO 3685. The surface roughness of the work pieces was found out using Surface Roughness Tester (Mitutoyo sj-201p). The wear mechanism was investigated in detail using Imaging method. Tool wear measurements demonstrate the capability of such tools in turning hard materials with reasonable tool life.It can be concluded that hard machining can be carried out for AISI 4340 hardened steel (46 HRC) with multilayer (Al_2O_3+TiC+TiN+AlCrN) coated ceramic tooling because the process has been proven to produce high productivity and functional performance of quality machined parts with respect to surface integrity.

Keywords: Ceramic tool, Wear, Coated, Uncoated, CNC Machine

1. Introduction

The introduction explains briefly all the terms related to project in order to understand this research. Special attention is directed toward the tool wear performance, coating and surface integrity. The aim is to illustrate the fundamental concepts that would be used to explain the results of this study.

The studies have shown that in the manufacturing industry a 30% reduction of tool costs, or a 50% increase in tool lifetime results only in a 1 % reduction of manufacturing costs. But an increase in cutting data by 20% reduces manufacturing costs by 15% [1]. In order to achieve higher productivity different approaches such as high performance cutting (HPC) and high speed cutting (HSC) can be chosen.

Recent Trends in Manufacturing by Machining. The recent development in science and technology has put tremendous pressure on manufacturing industries. The manufacturing industries are trying to decrease the cutting costs, increase the quality of the machined parts and machine more difficult materials. Machining efficiency is improved by reducing the machining time with high speed machining. When cutting ferrous and hard to machine materials such as steels, cast iron and super alloys, softening temperature and the chemical stability of the tool material limits the cutting speed. The productivity enhancement of manufacturing processes accelerates the development in design and evolution of improved cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance.

2. Literature Review

2.1 Introduction

Numerous studies have been carried outto describe the tool wear and wear mechanisms in the hard turning process. These studies can be categorized into four groups: (a) work piece material type (b) cutting tool type(c) cutting edge geometry (d) wear type and mechanisms [3]. Here the literature survey is done in following categories to find out the research gap, which is help full in this course of study.

2.2 Literature on Work Piece and Tool Material

Gabriela Strnad [1] performed a study in recent development in cutting tool material since 1970 to 2010 concluded that as recent development in the tool material is now focused on the development of hard material coating, to minimise the wear of the cutting tool. The repentantly multilayer monoblock coatings are mostly used due to their hot hardness, wear resistance and oxidation resistance properties.

Sahoo and sahoo [2] performed experimentation on machinability aspect of AISI 4340 steel using an uncoated and multilayer coated inserts. The machinability evaluated using flank wear, surface roughness and chip morphology. Experimental results revealed that multilayer TiN/TiCN/Al2O3/TiN coated insert performed better than uncoated and TiN/TiCN/Al2O3/ZrCN coated carbide insert being steady growth of flank wear and surface roughness. The tool life for TiN and ZrCN coated carbide inserts was found to be approximately 19 min and 8 min at the extreme cutting conditions tested. Uncoated Carbide insert used to cut hardened steel fractured prematurely. Abrasion, chipping and catastrophic failure are the principal wear mechanisms observed during machining. The turning forces (cutting force, thrust force and feed force) are observed to be lower using multilayer coated carbide insert in hard turning compared to uncoated carbide insert. Regression analysis done to validate the experimental results. The machining cost is calculated for both the tools TiN coated inserts saves the 93.4% than uncoated tool 40%.

Ashok kumarsahoo [3] done a comparative study on uncoated and multi-layered coated[TiN/TiCN/Al2O3/TiN] carbide tool having a hardness 1430 HV and1880HVrespectively.The work piece material was a high carbon high chromium AISI D2 steel having 26 HRC hardness the test is done under a dry environment. The tool life of TiN coated insert is found to be approximately30 times higher than the uncoated carbide insert under similar cutting conditions and produced lower surface roughness compared to uncoated carbide insert. The dominant wear mechanism was found to be abrasion and progression of wear was steady using multi layer TiN coated carbide insert. The statical validation is done using the regression analysis the model created shows 97.7% adequacy. The machining cost per part for uncoated carbide insert is found to be 10.5 times higher than the multi layer TiN coated carbide inserts. This indicates 90.5% cost savings using multilayer TiN coated inserts by the adoption of a cutting speed of 200 m/min coupled with a tool feed rate of0.21 mm/rev and depth of cut of 0.4 mm. Thus, TiN coated carbide tools are capable of reducing machining costs and performs better than uncoated carbide inserts in machiningD2 steel.

In hard material turning the input parameter are cutting speed, feed and depth of cut while the output parameter are tool wear, surface roughness and cutting forces developed during the machining operation. These input and output parameter can be correlated to establish the tool performance [6]. The investigation on the above said parameter is done by the R. Suresh et al on 4340 hardened steel having the 48 HRC hardness, using the multilayer (TiC/TiCN/Al2O3) coated carbide insert. The experiment was designed by using the taguchi L-27(313) orthogonal array. The correlations were established by multiple linear regression models. The linear regression models were validated using confirmation tests. The analysis of the result revealed that, the optimal combination of low feed rate and low depth of cut with high cutting speed is beneficial for reducing machining force. Higher values of feed rates are necessary to minimize the specific cutting force. The machining power and cutting tool wear increases almost linearly. With increase in cutting speed and feed rate. The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness. Abrasion was the principle wear mechanism observed at all the cutting conditions.

2.3 Literature on Wear type and mechanism

In machining a hard material having the hardness more than 60 HRC the CBN or PCBN tool are used [3]. K. aslant as used the mixed ceramic uncoated and the TiN coated insert to machine the AISI 52100 hardened steel with approximately 63 HRC hardness. According to the results obtained, fracture and chipping type damages occur more frequently in uncoated tools, whereas crater wear is the more common type of damage in TiN coated tools. In uncoated ceramic tool, the crater formation results in decrease of chip up-curl radius. Besides, uncoated cutting tool results in an increase in the temperature at the tool chip interface. This causes a thermal bi-metallic effect between the upper and lower sides of the chip that forces the chip to curl a smaller radius. Chips accumulate in front of the tool and stick to the work piece depending on the length of the cutting time. This causes the surface quality to deteriorate. TiN coating not only ensures that the cutting tool is tougher, but also ensures that the surface quality is maintained during cutting processes.

The mixed alumina ceramic is used by W. Grzesik [7] to machine a AISI 5140 steel with 60 HRC hardness, the wear analysis is done with SEM and X ray defraction method, finds the abrasion, fracture, plastic flow, adhesive tacking and material transfer and also tribochemical effects depending on the mechanical and thermal conditions generated in the machining tests.

Another one study done on the ceramic tool by A.Senthilkumar [8], compared the Ti[C, N] mixed alumina ceramic, SiC whisker reinforced alumina ceramic. The flank wear, crater wear and notch wear is calculated using SEM, Ti(C, N) mixed alumina tool performed well than SiC whisker reinforced alumina ceramic.

2.4 Literature on Methods used for design the experiment and wear analysis

To design the turning test the Taguchi orthogonal array is best suitable W.H.Yang,Y.S.Tarang [6].investigated the optimum level of parameters while machining the S45C steel with tungsten carbide tool using the taguchi method of design. The three levels of parameters are selected; the orthogonal array is selected based on the number of cutting parameters and number of levels.

The obtained results indicate that the feed rate was found to be the dominant factor among controllable factors on the surface roughness, followed by depth of cut and tool's nose radius. However, the cutting speed showed an insignificant effect. Furthermore, the interaction of feed rate/depth of cut was found to be significant on the surface finish due to surface hardening of steel. Optimal testing parameters for surface roughness could be calculated. Moreover, the second order regression model also shows that the predicted values were very close to the experimental one for surface roughness.

Flank wear measurement is mainly done with Scanning electron microscopy and profile projector. With development in technology the tool wear monitoring machine vision system comes in picture. Mainly there are two types online and offline T .Shelvraj presented an imaging method to measure the flank wear. This method is quiet easy than other traditional methods like SEM, x ray diffraction. In this study the wear is calculated by capturing an image of tool before and after machining using digital camera. With the help of matlab software the wear is calculated.

2.5 Summary of literature review

1) In the literature survey for hard turning process it is observed that the work piece material are heat treated material hardness is ranging from 26 HRC [5] to 63 HRC [3].
2) The most study is done on work piece material i.e. AISI 4340, AISI D2 steel, AISI 52100 steels.
3) [TiC/TiCN/Al2O3], Mixed alumina ceramic and coated ceramic tools [TiN] are mainly used.
4) The dry machining is mostly preferred only for Inconel 718 the wet machining is done.
5) Taguchi design method is preferred for design the experimentation using orthogonal array.
6) To validate the experimentation the regression analysis is used. ANOVA is used to investigate the effect of input machining parameter on output parameter.
7) To measure the flank wear the traditional methods are SEM, profile projector. Recently machine vision system is used to wear measurement online and offline.
8) The wear mechanism observed in uncoated carbide tool is premature fracture and chipping while progressive wear is observe red in coated carbide tools. For ceramic It was found that wear mechanisms observed in the machining tests involve abrasion, fracture, plastic flow, material transfer and tribochemical effects which appear depending on the mechanical and thermal conditions generated on the wear zones
9) Flank wear and surface are mainly considered to evaluate the performance of tool.

Literature review has indicated that considerable amount of research effort have been devoted to study the tool life and wear mechanism in hard tuning process. So far the wear resistance of multi-layered coated ceramic tools has not been completely studied in hard turning process.

3. Methodology

Based on the literature review and an examination of prior experimental studies, a methodology was developed to study the progression of flank wears of the cutting tools and the change in the surface roughness of the machined part in turning. The following steps that were taken to achieve the objectives of this study.

1) Experimentation based on taguchi orthogonal array.
2) Regression analysis to validate the experimental results.

3.1 Design of Experimentation using Taguchi orthogonal array

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community.

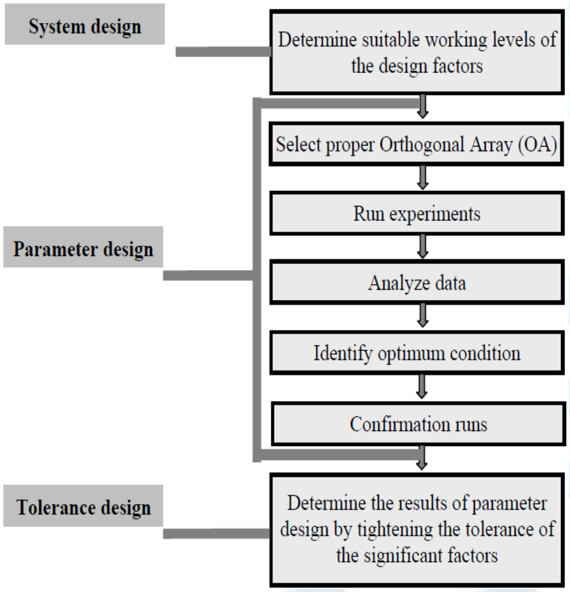

Fig 3.1-Flowchart of Taguchi Design

This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Signal to noise ratio and orthogonal array are two major tools used in design.

3.2 Tool Material Selection

For this study the ceramic is used as the tool material, the selection is based on the literature survey which indicate that least work is on the multi layered coated ceramic. The following are the important characteristic of the ceramic material. Every insert has a melting point, which reflects the temperature at which it is made. Ceramic's melting point (3,700° F) is higher than sintered carbide, which means it can be driven through the cut faster. Turning is an almost ideal operation for ceramics. In general, it is a continuous machining process that allows a single insert to be engaged in the cut for relatively long periods of time.

In most traditional metal cutting, heat is the enemy. It's bad for the tool and generally bad for the work piece (work hardening). The heat dissipation objective for most carbide cutting inserts is to get heat into the chip and quickly out of the cut zone, not so for ceramics.

3.3 Experimentation

The experimentation is carried in the following stages. The work piece material processed for machining, after that machining is carried out and the flank wear and surface roughness is measured.

3.3.1 Preprocessing

In preprocessing the raw material is cut to required size using cutting machine and turned on conventional lathe for heat treatment. The work piece material used was 50 mm in diameter and 100 mm long, with length to diameter ratio of the work piece material equal to 2.However, in order to meet the requirement of the ISO 3685 that the length to diameter ratio of the work piece material to be used should be less than 10 during testing, the bar was cut into 9 pieces (100 mm length) using the metal cutter shown in figure from Special Steel Stores.

Fig 3.2-Cutting of work piece material

After cutting work piece material on cutting machine, it was turned on lathe machine before giving for hardening.

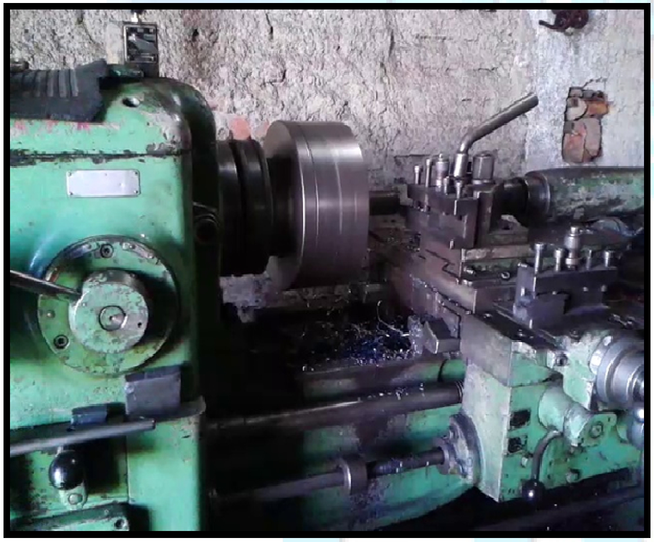

Fig 3.3-Turning the work piece material

After turning work piece material looked like as in figure shown below

Fig 3.4-Workpiece material after turning

3.3.2 Hardening process

AISI 4340 material was hardened to a value of 46 HRC.The hardening process is explained below.

3.3.3 Hardening

First, a piece of metal is heated gradually until it reaches a high temperature. When the entire sample reaches a high temperature, great heat intensity is applied to the area that will be hardened. When the steel reaches a temperature that causes it to turn red, it is removed from the furnace for quenching process.

Fig 3.5-Furnace in heat treatment plant

Heat AISI 4340 to 830- 860 degree Celsius hold until temperature is uniform throughout the section.

3.3.5 Tempering

Step three involves reheating the steel at the end which received the most intense heat in step one. The metal is heated until it turns the indicative blue colour, which means tempering has occurred and the heat source is cut off. The last step is to allow the new hardened and tempered steel to cool on its own. After that has taken place, hardened steel has been synthesized.

Fig 3.6 Tempering process Furnace in heat treatment plant

Re-heat AISI 4340 to 450-660 degree Celsius as required, hold until temperature is uniform throughout the section ,soak for 1 hour per 25 mm of section & cool in still air. After hardening material looked like as in figure shown below.

Fig 3.7 Hardened work piece material

The hardness achieved after the hardening process was 46 HRC.

3.4 Machining operation

The particular machining process selected for use in this project was a CNC turning operation. This process was chosen for several reasons. Turning is the most common single-point tool machining operation and has long been used as a basis for evaluating tool geometry and materials, work piece materials and tool life. Since CNC lathe tools are considerably less expensive than milling cutters or drills and because a large number of tools were utilized in gathering the data in this experiment, turning was selected for economic reasons as well as because of its simplicity and wide application.

Fig 3.8 CNC machine

3.4.1 Cutting Tool Insert

Commercially available uncoated and multilayer (Al_2O_3+TiC+TiN+AlCrN) coated ceramic tool inserts with external AlCrN layer were employed with geometry of TNGA 160408 for both.

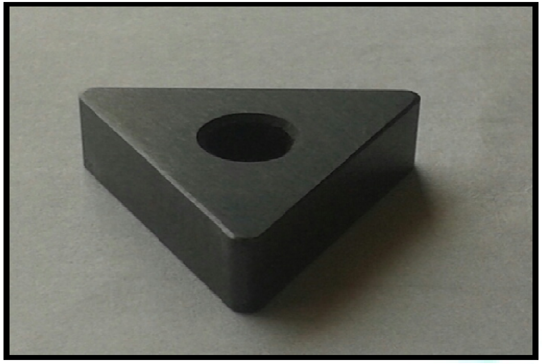

Fig 3.9 Cutting Tool

Designation of cutting tool inserts:

T: Triangle 60° (Shape)
N: 0° (Clearance)
G: ± 0.025 mm (Tolerance)
A: Cylindrical (Hole shape)
16: Length of cutting edge
04: Thickness
08: 0.8 mm (Corner radius)

3.4.2 Tool Holder

The following type of tool holder is used in experimentation.
MTJNL 2020 K 16 tool holder.

Designation of tool holder:

M: Multi-Lock (Holding method)
T: Triangle (Insert Geometry)
J: Side cutting edge angle offset (Tool style)
N: Negative (Insert clearance angle)
L: Left hand (Hand of tool)
20: Square size
20: Rectangle size
K: 25mm (Length of tool holder)
16: Cutting edge length (Insert size).

3.4.3 Experimental procedure

After heat treat the work piece was then set up on the CNC lathe machine

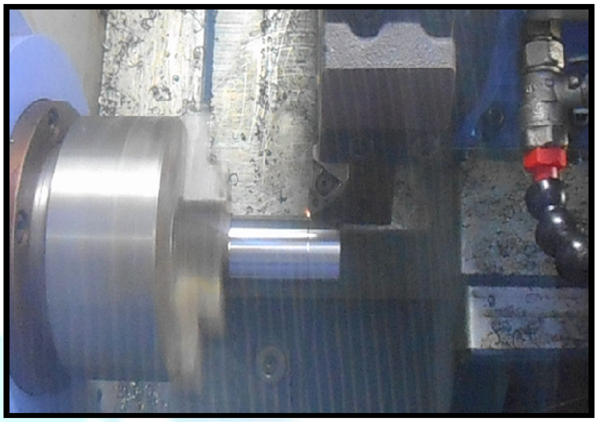

Fig 3.10 Experimentation

After experimentation, the tool holder was first removed from the CNC lathe, and the cutting tool was removed from the tool holder, by loosening the pin and clamp locks, in order to examine the flank wear using imaging method.

3.5 Tool wear measurement using imaging method

Tool wear is one of the most important aspects that affect tool life and product quality in machining. To study the wear mechanisms on the flank surface, a series of turning tests with AISI 4340 steel was performed at various speed, feed and depth of cut as similar for measurement of surface roughness. To identify the wear mechanisms that can be verified through the experiments, accurate measurement techniques are needed. In this project, photoFigs of tool wear were taken and wear was measured using imaging method with the help of MATLAB software.
The conventional way to characterize tool wear for a cutting operation is to perform cutting tests at constant cutting conditions and then tool wear is analyzed using indirect methods such as empirical formulae, and direct method such as tool maker microscope or graduated magnifying lens. The disadvantage of using such an empirical approach is that in order to achieve acceptable accuracy, this modeling procedure usually requires a large number of experimental tests and hence it is cumbersome and time-consuming.
In this study it was found that image processing method is easy and time saving.

4. Results and Discussion

4.1 Results

After experimentation the results obtained for flank wear and surface roughness are given below.

Table 4.1: Tool wear results

Sr. No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Wear (mm)	Wear (mm)
				Uncoated	Coated
1	125	0.10	0.25	0.291	0.041
2	125	0.16	0.40	0.318	0.098
3	125	0.25	0.63	0.376	0.159
4	150	0.10	0.40	0.4833	0.180
5	150	0.16	0.63	0.526	0.244
6	150	0.25	0.25	0.570	0.256
7	175	0.10	0.63	0.639	0.364
8	175	0.16	0.25	0.570	0.377
9	175	0.25	0.40	0.538	0.371

4.2 Discussion

4.2.1 Wear chart (Uncoated)

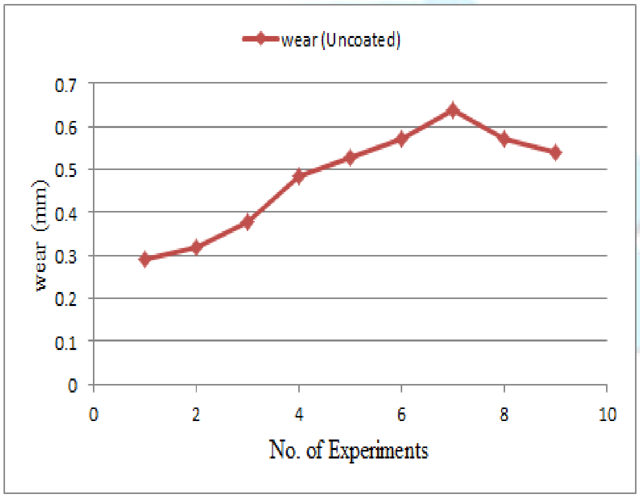

Fig 4.1 Chart of wear (uncoated) v/s. No. of Experiments

The above Fig is of uncoated insert for wear. The x axis represents Experiment No. and the y axis represents the wear value. From the Fig it can be observed that for 1st condition the wear is minimum (i.e.0.291 mm) while for 7th condition the wear is maximum (i.e.0.639 mm). The criteria recommended by ISO 3685:1993 to define the effective tool life is VBB, max = 0.6 mm. Hence, the value of wear exceeds the limiting value for 7th condition. The nature of Fig indicates that the wear is progression type of flank wear.

4.2.2 Wear chart (Coated)

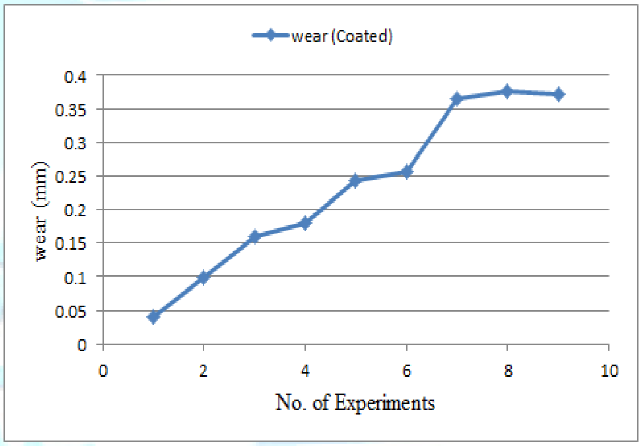

Fig 4.2 Chart of wear (coated) v/s. No. of Experiments

The above Fig is of coated insert for wear. The x axis represents Experiment No. and the y axis represents the wear value. From the Fig it can be observed that for 1st condition the wear is minimum (i.e. 0.041 mm) while for 8th condition the wear is maximum (i.e.0.377 mm). The criteria recommended by ISO 3685:1993 to define the effective tool life is VBB, max = 0.6 mm. Hence, the value of wear does not exceed the limiting value for all the condition. Thus, we conclude that there was no tool failure for all the conditions. The nature curve obtained shows the linear progression in flank wear.

4.2.3 Comparative chart for tool wear of coated and uncoated

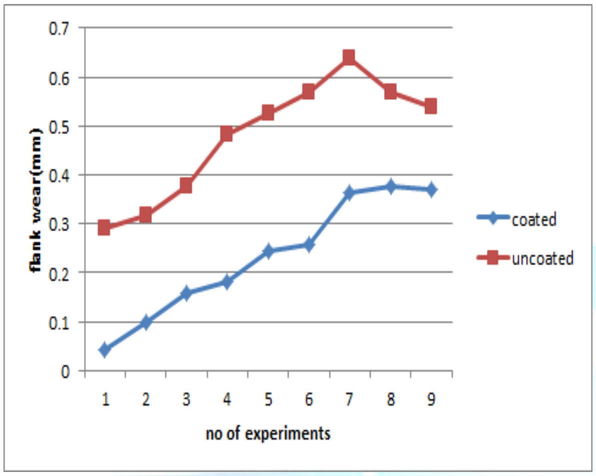

Fig 4.3 Chart of wear v/s. No. of Experiments

The above Fig is of coated insert for wear. The x axis represents Experiment No. and the y axis represents the wear value. The red curve represents the values of wear for different conditions of uncoated insert and the blue curve represents the values of wear for different conditions of coated insert.

From the above Fig it is clear that, the wear is less for coated insert than the uncoated. At the first cutting condition the wear for uncoated is 0.291mm while for coated it is 0.04mm. The maximum flank wear is observed at 7th condition, for uncoated 0.639 and 0.364 for coated.

5. Conclusions

Multilayer coated and uncoated ceramic inserts have been assessed with respect to flank wear and surface roughness. Regression models have been developed and comparisons between both inserts have also been made. The results of the findings are presented. Conclusions including aspects related to tool wear, surface roughness.

1. From result obtained the highest and lowest tool wear for multilayer coated and uncoated ceramic tools are given below

Cutting condition	Flank wear	
	Coated	uncoated
7th	0.364 max	0.639 max
1st	0.41 n	0.291n

2. During machinability study in hard turning. It is observed that, the tool life for multilayer TiN+ AlCrN coated ceramic insert is higher than the uncoated ceramic insert under extreme cutting conditions of hard turning of AISI 4340 steel (46 HRC). The uncoated ceramic insert fails (for 7th condition) as it exceeds the maximum value for flank wear in hard turning at extreme parametric range selected

6. References

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