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Tool life Optimization in turning operations using uncoated carbide tool inserts and multi-layer hard surface coated carbide cutting tool

Praveen Kumar[1], Mr. Sanjeev[2]

[1]M.Tech Research Scholar, CBS Group of Institutions, Jhajjar
[2]Asst. Professor, CBS Group of Institutions, Jhajjar

ABSTRACT

In this paper, our work focuses on the optimization of cutting tool life of a CNC turning machine and Lathe turning operation is performed on it by using uncoated carbide tool inserts and multi-layer hard surface coated (TiN) carbide cutting tool. as work piece material to predict the tool life. Data is collected from CNC turning machine which is run by different samples of experiments using software. The input of the model consists of feed rate, cutting speed and depth of the cut while the output from the model is the Tool life which is calculated by Taylor's tool life equation. This research is to test the collecting data by ANOVA. The model is validated through a comparison of the experimental values with their predicted counterparts. The optimization of the tool life is studied to compare the relationship of the parameters involved. The result of the analysis shows that depth of cut was the only parameter found to be significant. The analysis also shows that the predicted values and calculated values are very close, that clearly indicates that the developed model can be used to reduce the cost of turning.

Key Words: ANOVA, RSM, CVD, PVD, WC, HB, UCC, CNC.

INTRODUCTION

The recent developments 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 imposes the acceleration of the design and evolution of improved cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance. Because of the highly non-linear nature of metal cutting and the complex coupling between deformation and temperature fields, a complete understanding of the mechanics of metal cutting is still lacking and is thus the topic of great deal of current research. High speed machining has been the main objective of the Mechanical Engineering through ages. The trend to increase productivity has been the instrumental in invention of newer and newer cutting tools with respect to material and designs.

High speed machining is not associated with increased productivity and better surface finish rather associated with a great amount of heat generation. Therefore, it is necessary for tool materials to possess good high-temperature, mechanical properties and sufficient inertness. While many ceramic materials such as TiC, Al_2O_3 and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi- layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials. The majority of cutting tools in use today employ chemical vapour deposition (CVD) or physical vapour deposition (PVD) hard coatings. The high hardness, wear resistance and chemical stability of these coatings offer proven benefits in terms of tool life and machining performance.

The first technique is the CVD. This method deposits thin films on the cutting tools through various chemical reactions. Most tool coatings were traditionally deposited using the CVD technique until the recent development of PVD. This method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation. Coated hard metals have brought about tremendous increase in productivity since their introduction. Since then coatings have also been applied to high speed steel and especially to HSS drills. Coatings are diffusion barriers, they prevent the interaction between chip formed during the machining and the cutting material itself. The compounds which make up the coatings used are extremely hard and so they are very abrasion resistant. Typical constituents of coating are Titanium Carbide(TiC), Titanium Nitride (TiN), Titanium Carbonitride (TiCN) and alumina (Al2O3).

Objective of the paper

- The primary objective is to evaluate the coated tool in hard machining under extreme conditions of machining to optimize it's parameters and
- To evaluate the performance in a systematic way of such tool to find its application in a brooder area including for CNC machining.

Keeping the above objective for the work, the experimentation has been planned to carry out .The performance test of uncoated and coated tools both for soft and hard machining. In soft machining materials like Al, soft and abrasive material like Al-Si alloy and hard material like AISI 4340 steel has been planned for the experimental.

2. LITRATURE REVIEW

J. wang (2000) studied the effects of the multi-layer hard surface coating of cutting tools on the cutting forces in steel turning are presented and discussed, based on an experimental investigation with different commercially available carbide inserts and tool geometries over a range of cutting conditions.

R. Suresh et. Al (2002) Hard turning with multilayer coated carbide tool has several benefits over grinding process such as, reduction of processing costs, increased productivities and improved material properties. The objective was to establish a correlation between cutting parameters such as cutting speed, feed rate and depth of cut with machining force, power, specific cutting force, tool wear and surface roughness on work piece. In the present study, performance of multilayer hard coatings (TiC/TiCN/Al2O3) on cemented carbide substrate using chemical vapor deposition (CVD) for machining of hardened AISI 4340 steel was evaluated. An attempt has been made to analyze the effects of process parameters on machinability aspects using Taguchi technique. Response surface plots are generated for the study of interaction effects of cutting conditions on machinability factors.

M.Y. Noordin et. Al (2004) studied the performance of a multilayer tungsten carbide tool was described using response surface methodology (RSM) when turning AISI 1045 steel. Cutting tests were performed with constant depth of cut and under dry cutting conditions. The factors investigated were cutting speed, feed and the side cutting edge angle (SCEA) of the cutting edge.

J.A. Ghani et. Al (2004) studied the wear mechanism of TiN-coated carbide and uncoated cermets tools were investigated at various combinations of cutting speed, feed rate, and depth of cut for end milling of hardened AISI H13 tool steel. The cutting speed is used for semi-finishing and finishing for the said material at high cutting speed regime.

Renato Franc¸oso de Avila et. Al (2006) studied the performance of uncoated and coated carbide tools (ISO grade K10) with a 3m thick monolayer of TiN (produced by PAPVD) when continuous turning AISI 8620 steel.

Jorge A. Olortegui-Yume et. Al (2007) Steady-state turning experiments were carried out with multilayer coated inserts consisting of TiN/Al2O3 /TiCN deposited on a carbide substrate. Confocal microscopy was used for the first time to observe the topography of crater wear evolution in multilayer coated inserts.

A. Devillez et. Al (2007) studied the machining of heat resistant super alloys used in aeronautical applications and classified as difficult-to-machine materials, the consumption of cooling lubricant during the machining operations is very important.

R.F.´Avila et. Al (2008) One of the criteria employed for analyzing cutting tool life used for cemented carbide tools is the depth of the crater (KT) located on the rake face, given as a function of the feed rate.

A.K. Chattopadhyay ET. AL (2009) has conducted to study wetting characteristics of aluminium towards different cutting tool materials for assessing the compatibility for dry machining of aluminum.

Muammer Nalbant et. Al (2009) studied the machining of AISI 1030 steel (i.e. orthogonal cutting) uncoated, PVD- and CVD-coated cemented carbide insert with different feed rates of 0.25, 0.30, 0.35, 0.40 and 0.45 mm/rev with the cutting speeds of 100, 200 and 300 m/min by keeping depth of cuts constant (i.e. 2 mm), without using cooling liquids has been accomplished.

W.Y.H. Liew (2010) evaluated the performance of TiAlN/AlCrN nano-multilayer coated, TiAlN single-layer coated and uncoated carbide tools in low-speed milling of STAVAX (modified 420 stainless steel) under flood and mist lubrication. Scanning electron microscope, energy dispersive X-ray analysis system and Raman spectroscopy were used to examine the tool wear and determine the type of oxide formed on the tool surface during machining. In machining STAVAX with a hardness of 40 HRC, the coated tools were subjected to delamination, attrition and abrasive wear throughout the duration of testing.

Abhay Bhatt et. Al (2010) found the results of an experimental investigation on the wear mechanisms of uncoated tungsten carbide (WC) and coated tools (single-layer (TiAlN) PVD, and triple-layer (TiCN/Al2O3/TiN) CVD) in oblique finish turning of Inconel 718. Tool wear rate and wear mechanisms were evaluated for cutting speeds, 50oVo100 m/min, and feed rates, 0.075ofo0.125 mm/rev, at a constant depth of cut of 0.25 mm.

Simranpreet Singh Gill et. Al (2011) Cryogenic treatment has been ascribed as a way of improving the cutting life of tungsten carbide turning inserts. Most of the research conducted till date has not reported any effort to excavate the effect of cryogenic treatment on the performance of coated tungsten carbide inserts in terms of adhesion strength of coatings deposited on tungsten carbide substrate.

Ashok Kumar Sahoo et. Al (2012) The present work deals with some machinability studies on flank wear, surface roughness, chip morphology and cutting forces in finish hard turning of AISI 4340 steel using uncoated and multilayer TiN and ZrCN coated carbide inserts at higher cutting speed range.

Ashok Kumar Sahoo et. Al (2012) presented the mathematical modelling and parametric optimization on flank wear and surface roughness based on response surface methodology and grey-based Taguchi method in finish hard turning of AISI 4340 steel (HRC 47 ± 1) using multilayer coated carbide (TiN/TiCN/Al2O3/TiN) insert under dry environment. The economical feasibility of utilizing multilayer TiN coated carbide insert has been described.

Satish Chinchanikar et. Al (2013) presented work performance of coated carbide tool was investigated considering the effect of work material hardness and cutting parameters during turning of hardened AISI 4340 steel at different levels of hardness.

F. Koné et. Al (2013) presented an analysis of experimental cutting forces and the study of the chip flow angle when machining 304L austenitic steel with a groove coated tool under dry condition. Experiments were conducted on a wide range of cutting conditions with a particular attention to ensure a great confidence in the obtained results.

3. EXPERIMENTAL INVESTIGATION

The **experimental work** was **divided** into **three phases**: the **first phase**, **turning of AISI 4340 steel** was carried out with uncoated and multilayer TiCN+TiC+TiCN+Al2O3 +TiN-coated carbide tool with external TiN layer. In the **second phase**, **turning of soft material (Aluminium)** was carried out with uncoated carbide inserts and in the **third phase turning of soft and abrasive material (Al+5% Si)** was carried out with uncoated carbide inserts.

Machining of hard material (AISI 4340 Steel)
The present work deals with the turning of hard material such as AISI 4340 steel. It is an important engineering material employed in manufacturing of components in auto and aerospace industries. Since the present trend in the manufacturing industry is high speed dry machining, it was applied to evaluate the performance of coated tools in typical manufacturing processes.

Work material
A solid bar of AISI 4340 steel with 37 mm diameter, 160mm long and of 45 HRC were used as workpiece (Fig1).

Fig.1.AISI 4340 steel bar

Table.1.The chemical composition of AISI 4340 steel in percentage by weight

C	Si	Mn	P	S	Cr	Ni	Mo	Fe
0.382	0.228	0.609	0.026	0.022	0.995	1.514	0.226	95.998

Cutting tools

Commercially available uncoated and multilayer TiCN+TiC+TiCN+Al2O3+TiN-coated carbide tool inserts with external TiN layer were employed with geometry of DCMT 11T304- THM and DCMT 11T304-TN 2000 respectively.

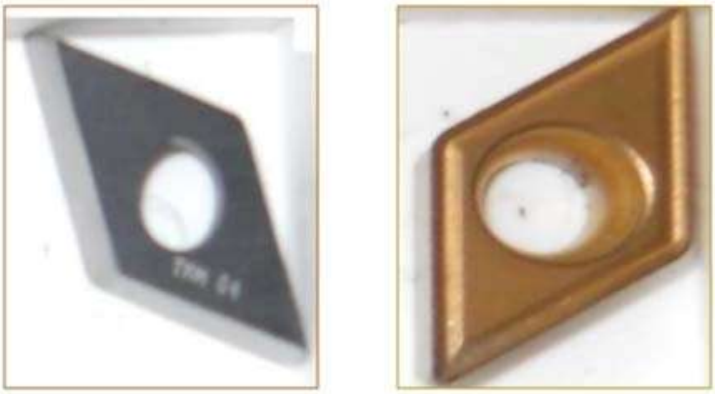


Fig.2.Uncoated and multilayer coated carbide inserts

Table.2.Chemical composition of carbide tools (% wt)

Co	Cr3C2	WC
6	0.5	93.5

Machine tools

Cutting tests were carried out on a Capstan lathe machine under dry conditions.

Fig.3. the capstan lathe

Fig.4.The work piece and tool setup

Table.3.Conditions For The Cutting Test

Sl. No.	Cutting Condition	Description
1	Workpiece	AISI 4340 Steel
2	Cutting Inserts	Uncoated CarbideTiN Coated carbide
3	Diameter of w/p	37 mm
4	Length of W/p	160 mm
5	Hardness	45 HRC
6	Cutting Speed	80-160 m/min
7	Feed	0.06- 0.18 mm/rev
8	Depth of cut	0.02 mm
9	Cutting Environment	Dry

Tool wear measurement

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 study photographs of tool wear were taken using SEM and an optical microscope.

Design of experiment

The present experimental investigation deals with the analysis of the experiment by the taguchi methodology, Taguchi analysis consists of the orthogonal arrays. A L 16 orthogonal array (OA) has been used to determine the importance of the factors or the parameters. Taguchi's design of experiment with a standard orthogonal array L 16 was used because of its minimum number of required experimental trials and yet gave a satisfied result. The L 16 OA has sixteen rows corresponding to sixteen sets of variables setting. Each row of the matrix represents one trial. However, the sequence in which those trials were carried out was random. Sixteen experiments with combination of different cutting parameters were randomly repeated. Four levels of cutting speeds, feed rates and depth of cuts were tested. Factors and levels used in the experiment are shown in Table 4.

Table 4. Factors and levels used in the experiment

	Level			
Factors	1	2	3	4
Cutting speed (mm/min)	80	105	130	160
Feed rate (mm/rev)	0.06	0.08	0.12	0.16
Depth of cut (mm)	0.2	0.3	0.4	0.5

Machining of soft material (Aluminium)

In this experiment a pure aluminium rod having length of 70mm and diameter 25.4mm was machined in step wise manner in CNC turning machine. The step turning was done at different speeds and feeds keeping the depth of cut constant.

Table.5. Cutting condition for turning aluminium

No of cut	Speed(rpm)	Feed(mm/min)	Depth of cut(mm)
1	1500	15	
2	1250	35	0.5
3	1000	55	

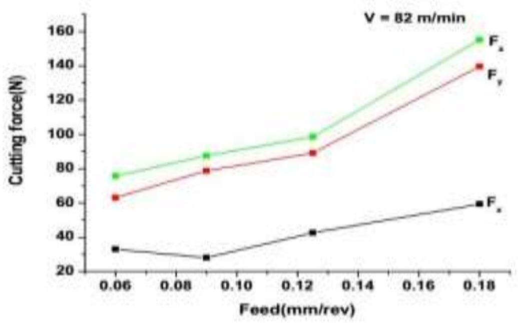
Machining of soft and abrasive material (Al+5%Si)

For this experiment the specimen was prepared by sand casting process (Fig.5). Small pieces of aluminium of weight 300 gm were melted in an electric arc furnace maintaining the temperature at 877 0 C. Then 5 wt% of silicon powder was added to the molten aluminium and stirred manually by a stirrer. Then it was poured by the crucible through the pouring basin into the mould and casted.

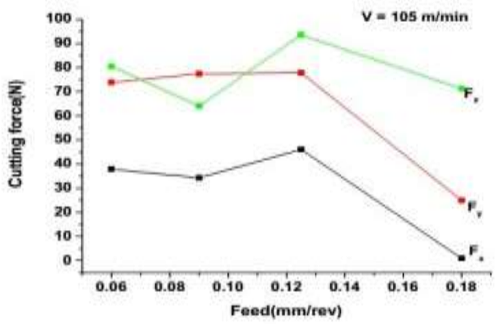
Fig.5.The casting process of aluminium-silicon alloy

4. RESULTS AND DISCUSSION

Results of cutting tests are presented in terms of graphs in Fig. 4. and Fig. 5 , which shows the variation of different forces with different cutting speed and feed or the uncoated tool. The result for multilayer coated tool are given in The results present the variation of cutting forces under feed rates of 0.06, 0.09, 0.125 and 0.18 mm/rev and various cutting speeds such as 82,105,130 to 160 m/min. For the 0.06 mm/rev feed rate and the uncoated tool (fig4.2 (a)), the forces decrease with the increase in cutting speed and their values are in the range 20 – 80 N. For the same feed rate, the forces measured with the coated tools are relatively low in the range 20 – 65N This is probably due to the increasing heat generated at cutting tool tip and softening of work material at higher speeds. The shape of the cutting forces curves depends on the tool. The differences detected may be surely explained and correlated to the wear mechanisms developed during the tests and observed on the rake and flank faces of the tool Yang, K., Jeang, (1994) ,Prengel, H. G., Pfouts, W. R (1998). For all the coated tools, the cutting forces are lower than the uncoated tool.



(a)



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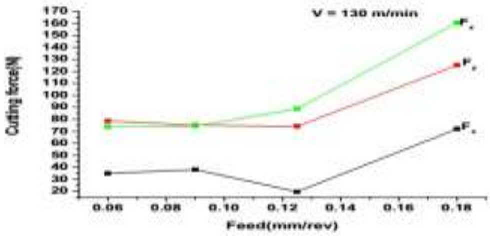

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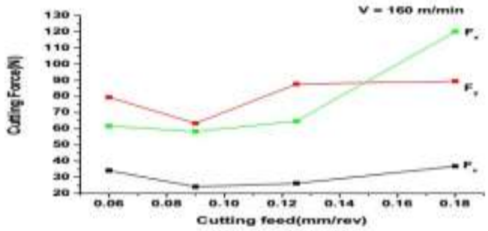
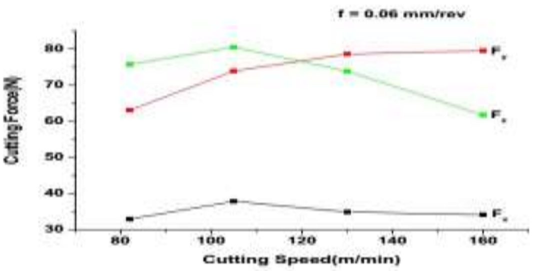


(d)

Fig. 6.Effect of speed on different forces for uncoated insert



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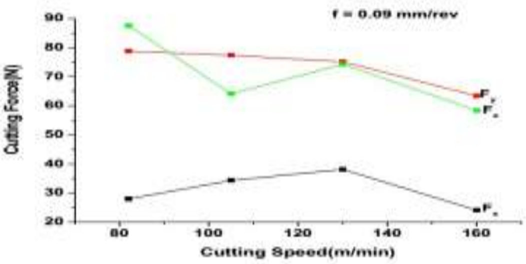

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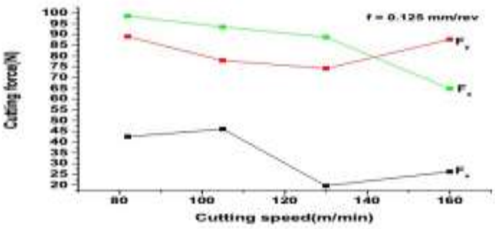

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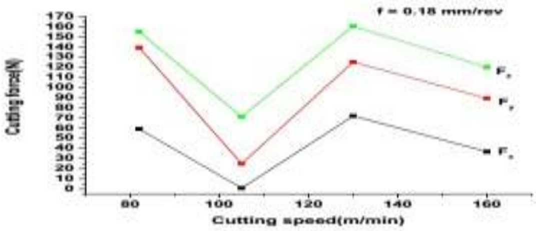


(d)

Fig.7. Effect of feed on different forces for uncoated insert.

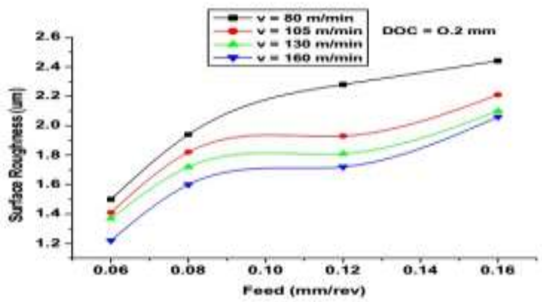
Surface roughness measurement

Surface finish in turning has been found to be influenced by a number of factors such as cutting speed, feed rate and depth of cut. The various simple surface roughness parameters used in the industries such as average roughness (Ra), root mean square RMS and maximum peak to valley.

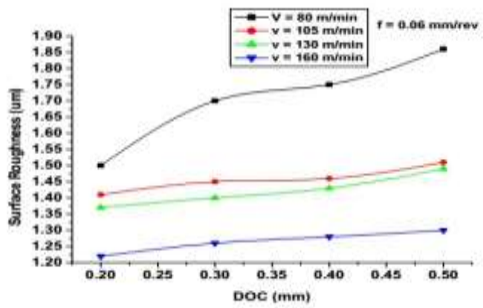
The theoretical arithmetic average surface roughness: $Ra = 0.032\ f^2/ R$ (1)

Where f= feed rate (mm/rev) and R= tool nose radius (mm). It means that surface roughness increases with increasing feed rate and a large tool nose radius reduce surface roughness of the work piece.

Results of surface roughness tests are presented in terms of graphs. The Fig.7 shows the graphical representation of cutting speed, feed rate and depth of cut Vs surface roughness at cutting speeds of 80, 105, 130 and 160 m/min with feed rates of 0.06, 0.08 ,0.12 and 0.16 mm/rev and depth of cut of 0.2,0.3,0.4 and 0.5 mm.



(a)



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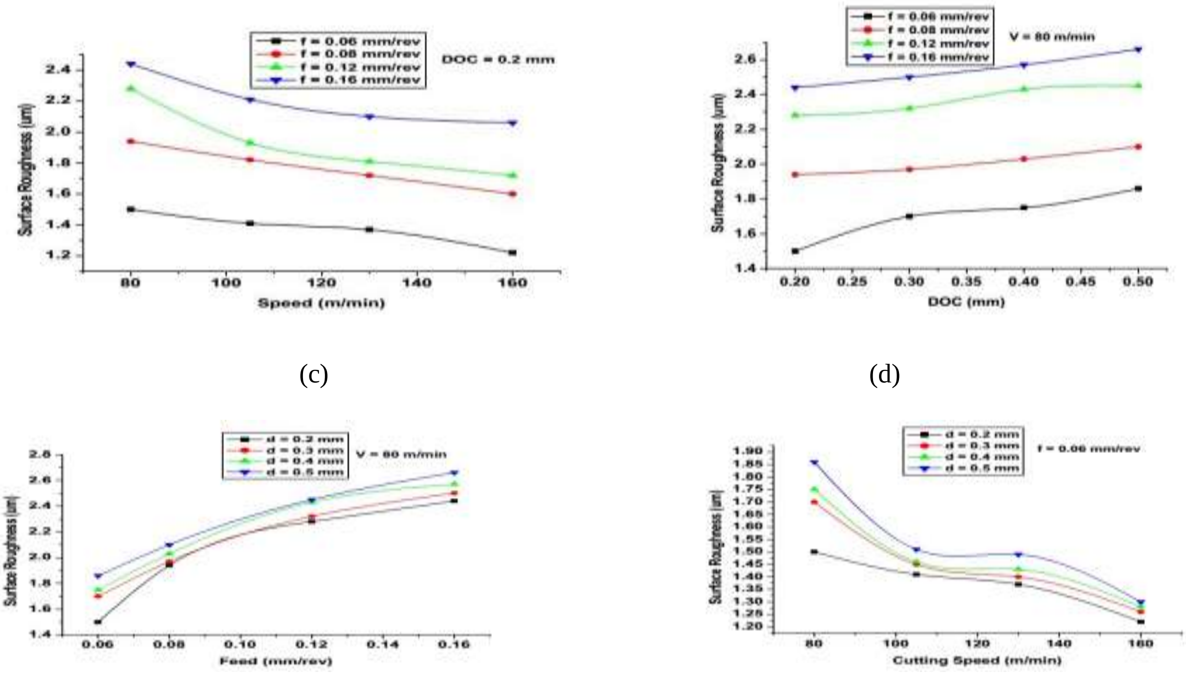

(c) (d)

(e) (f)

Fig.8. The variation of average surface roughness with cutting speed, feed rate and depth of cut when machining 4340 steel

Tool wear measurement

The mechanisms involved in the wear of cutting tools, especially in hard machining, are rather complicated and may include different interacting effects linked together in a complex manner. Primarily, depending on cutting conditions, work material, and tool material, the performance of the tool is limited by flank wear, crater wear, edge chippings, nose wear, or combination of these. Tool wear depends on the tool, work piece material (physical, mechanical and chemical properties), tool geometry, cutting parameters, cutting fluid, etc. Crater wear occurs on the rake face of the tool. The crater wear affects the tool geometry. The most important factors influencing crater wear was temperature at the tool tip interface and the chemical affinity between tool and work piece materials.

SEM photograph of uncoated carbide inserts. The wear either occurs gradually by abrasive or adhesive wear, through plastic deformation, by more discrete losses of material through discrete fracture mechanism, or by combination of these. Those effects could be due to high mechanical, thermal, and chemical loads generated during hard machining. Capability to predict tool wear during hard turning is necessary to determine the optimum cutting variables. It is also useful to avoid catastrophic tool failure, which can damage the workpiece surface and affect the machine tool performance.

CONCLUSION

Based on the experimental results presented and discussed, the following conclusions are drawn on the effect of cutting speed and feed on the performance of uncoated and multi-layer coated carbide tools when turning AISI 4340 steel and performance of uncoated carbide tools when turning aluminium and aluminium-silicon alloy.

1. Coated carbide tools perform better than uncoated carbide tools as far as cutting forces are concerned. For average magnitudes of forces obtained with uncoated carbide tool were higher than those obtained with coated carbide tools under experimental conditions.
2. A cutting speed of 160 m/min has resulted in optimized value of cutting forces in the experimental range. Cutting feed has a direct effect on cutting force. As the feed increases there is a direct increase in the cutting forces.
3. 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.
4. This study concluded that the multilayer TiCN+TiC+TiCN+Al2O3+TiN-coated carbide tool with external TiN layer produce better surface roughness with respect to high speed and low feed rate. But the depth of cut has minimum effect on surface roughness. The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness.

5. Microscopic analysis of the worn surfaces on the cutting tools showed significant wear of the TiN cutting tools due to abrasion. Abrasion was the principal wear mechanism observed at all the cutting conditions. The coated carbide tool was worn due to progressive wear of the protective coating. The cutting tool wear increases almost linearly with increase in cutting speed and feed rate.
6. Results show that, the machining of hard materials at higher speeds is improved by using coated tools. From the experimental investigation it is observed that coated tools give better results as compared to uncoated tools in turning.
7. The uncoated tools have successfully have been employed for machining of soft ductile material like Al and soft and abrasive material like Al-Si alloy. The surfaces obtained under dry machining has been found to be acceptable. However, surfaces produced for Al-Si alloy is not good. Thus better tool and work combination may be used like PCD tools/diamond coated tools.

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