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### Effect of Cutting Parameters on Tool Wear of Coated Carbide Tool in Hard Turning of AISI 4340

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#### Abstracts

The use of high strength and heat resistant materials is increasing day by day in aerospace, automotive, steam turbines and nuclear applications. This paper presents an experimental investigation of finish hard turning under dry conditions using coated carbide tools. In this study the effect of workpiece hardness, cutting speed and feed on tool wear during turning of hardened AISI 4340 steel has been reported. Workpiece hardness and cutting was observed to be a highly significant factor to affect the tool performance. Finally different wear mechanisms under different conditions were reported. It has been observed that catastrophic tool wear occurred particularly at highest cutting speed used. Further the tool wore rapidly at high degree of workpiece hardness.

**Keywords:** Turning Machinability, Hardened steel, coated carbide tools, Tool life, Wear mechanisms.

#### Introduction

These days materials having higher strength with high melting temperatures are preferably used for variety of applications like aero engines/ steam turbines/ Bearing industry and other automotive related applications [1,2]. These materials include super-alloys, refractory metals and hardened steels etc [3,4]. Thus during machining of these materials friction and heat generation at the cutting zone are the frequent problems, high cutting forces and poor surface characteristics are common [5]. The preferable tool material used for machining of these work materials is CBN tool. CBN has hardness and wear resistance second only to diamond and it has a good thermal resistance, a high coefficient of thermal conductivity, good chemical stability and high hot hardness [4]. But the cost associated with manufacturing of CBN tool materials is very high, which has focused the attention of researcher to look for economical tool material alternate. Within a particular range of workpiece hardness, coated carbide has been explored in hard turning, which are quite economical in comparison to the CBN. Author investigated the performance of coated carbide, CBN-H and mixed ceramic tool in hard turning of W320 steel with five values of speed (60,90, 120, 150, 200 m/min) with three values of feed (0.03,0.06, 0.1 mm/rev) at constant depth of cut of 0.1mm. The results indicated that the performance of coated carbide tool was comparable with that of CBN up to speed of 120m/min. At the highest cutting speed, performance of coated carbide tools deteriorated drastically, on the other hand CBN tool gave optimum performance [6]. Lot of work has been reported in the past in order to improve the effectiveness of machining

of hard to machine materials but particularly with CBN and ceramic tools. Further the work related to testing the performance of carbide tools in hard turning is scant. Thus in this study the aspects related to tool performance like, the tool life and tool wear mechanisms during turning of hardened AISI 4340 steel at three levels of hardness: 40, 47 and 54 HRC, respectively, using CVD applied multi-layer TiCN/Al<sub>2</sub>O<sub>3</sub>/TiN. This work also study the affect of variation of cutting speed , feed and degree of workpiece hardness on tool life Different tool wear mechanisms considering the effect of work material hardness, cutting speed and feed are discussed with the images taken by digital and scanning electron microscope

#### Experimental procedures

In the present study it is decided to investigate the effect of cutting parameters (ie cutting speed, feed, depth of cut and workpiece hardness) on tool flank wear and surface roughness during hard turning of AISI 4340 tool steel with coated carbide insert. The hardness of the workpiece used in this study was 40, 47 and 54 HRC. The variation in hardness of workpiece material was not more than  $\pm 1$  HRC.

The hard turning was conducted on CNC lathe machine. Workpiece material selected for study in the form of round bar of 270 mm long and 30 mm diameter, so that L=D ratio should not exceed 10 as per the ISO standard. [7] As recommended by the tool manufacturer the inserts used in this study having grade CNMG120408-QM (C-4025) with internal layer coating of TiCN, intermediate

coating of  $Al_2O_3$  and outer most coating layer of TiN (Titanium Nitride) [8]. Coated carbide inserts used in this study having 0.8 mm nose radius were selected. During hard turning cutting speed is the most dominant factor influencing tool life, followed by hardness and feed [5,9]. In this study, on the basis of literature and recommendations of the tool manufacturers the cutting speeds selected were 80m/min, 140m/min and 200m/min The feed were 0.08,mm/rev, 0.15mm/rev and 0.22 mm/rev and depth of cut as 0.2mm, Hardness of the workpiece were 40,47 and 54 HRC [5,8]. As shown in Fig .1 the tool flank wear in all the cases were not uniform on the cutting edge. Thus instead of VBavg, VBmax was preferred in this study. A flank wear criterion of VBmax=0.2mm was chosen to evaluate the tool life. The selection of low VBmax, instead of VBmax=0.6mm stipulated in ISO 3685 [7], is consistent with finish hard turning applications.



Fig.1 Coated carbide tool after 6min of machining at  $v=80m/min, f=0.08mm/rev$  and  $W.H=40HRC$

Each single pass consisted of axial cutting length 200mm and after every 100mm of workpiece length, the amount of maximum flank wear (VBmax) was recorded. The experiment was terminated when the following condition was arrived:  $VB_{max} \geq 200$  mm. Maximum tool flank wear was measured using optical microscope having image analysis software. The worn tools were also evaluated using scanning electron microscope (SEM) at regular intervals in order to understand the wear modes and mechanisms that affect the tool performance.

**Results and discussions**

In this section, experimental findings are presented. Plots showing the, tool at three levels of workpiece hardness, cutting speed and feed are presented. Wear

mechanisms of tools under different cutting regimes are explained with the help of SEM and a digital microscope images.

*A. Analysis of Tool wears*

According to standard ISO 3685, the time at which the tool ceases to produce a workpiece of desired size and surface quality usually determines the end of useful tool life [7]. Maximum tool flank wear was measured using optical microscope having image analysis software. The worn tools were evaluated using scanning electron microscope/ microscope at regular interval in order to understand the wear modes and mechanisms that affect the tool performance. Each set of experiments replicated twice and average value of VBmax was evaluated. Progression of maximum flank wear (VBmax) with machining time in minutes at different cutting speeds and feed rates with different levels of workpiece hardness is presented in Figs. 2(a,b,c) and 4(a,b). From the graphs it is indicated that in all cases tool life is significantly affected by degree of workpiece hardness followed by cutting speed and then by feed rate [5, 6]. At low and medium cutting speed, the progression of flank wear in first few minutes of machining was gradual. In all the cases tool life of carbide inserts decreases as the cutting speed increases for all feed rates and workpiece hardness because with increase in cutting speed for a given time the cutting temperature increases, which leads to rapid tool [4, 7]. At the highest speed used the tool life was low in comparison to other two speed selected. The maximum tool life was achieved at lowest degree of workpiece hardness, because the material strength to be machined is low at low degree of hardness, which resulted in longer tool life [10]

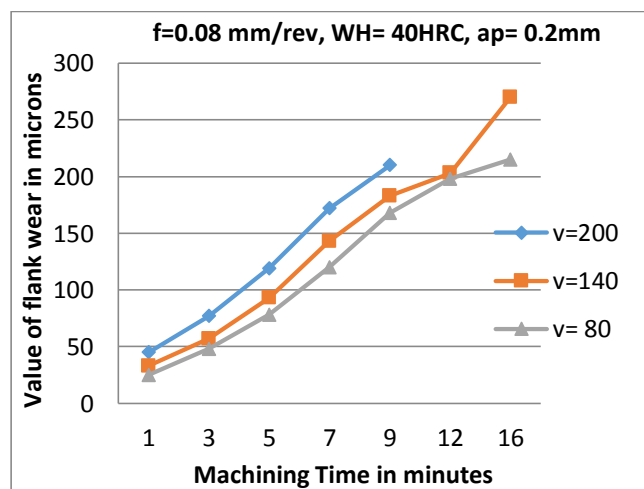


Fig.2(a) Progression of tool life at  $f=.08mm/rev, WH=40HRC$  on different cutting speeds

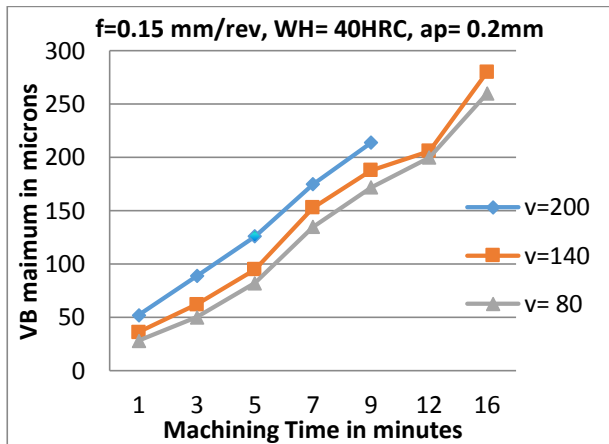


Fig.2(b) Progression of tool life at f=.15mm/rev, WH=40HRC on different cutting speeds

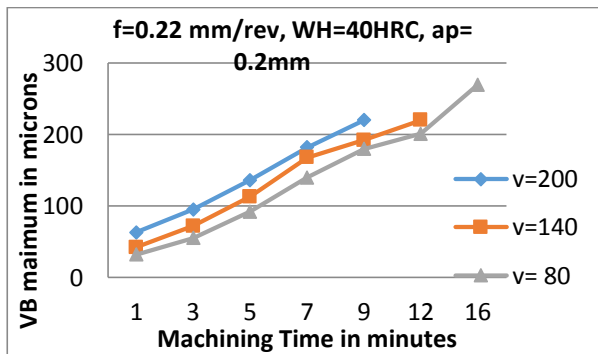


Fig.2(c) Progression of tool life at f=.22mm/rev, WH=40HRC on different cutting speeds

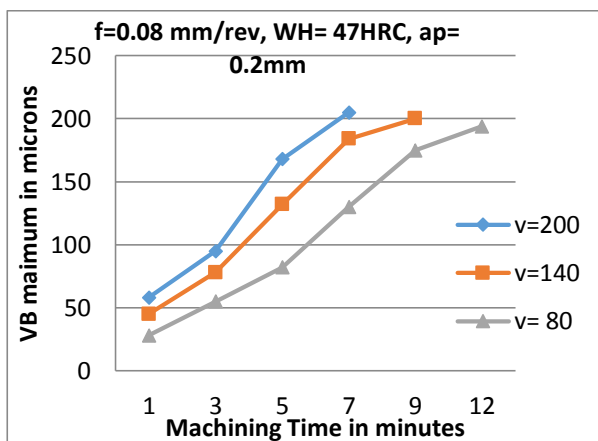


Fig.3(a) Progression of tool life at f=.08mm/rev, WH=47HRC on different cutting speeds

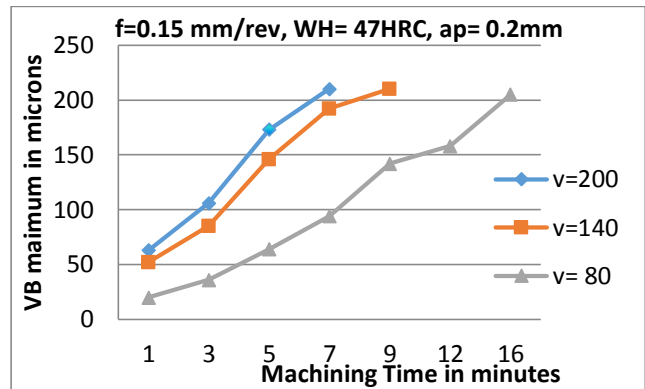


Fig.3(b) Progression of tool life at f=.15mm/rev, WH=47HRC on different cutting speeds

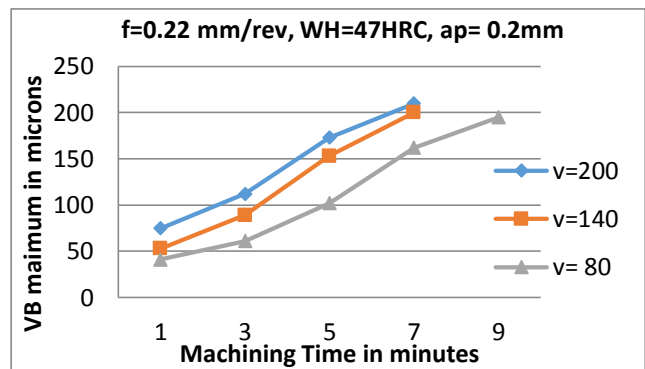


Fig.3(c) Progression of tool life at f=.22mm/rev, WH=47HRC on different cutting speeds

At highest degree of workpiece hardness, the tool life achieved under all circumstances was very short. Because at highest speed the mechanical and thermal loading led to deterioration the tool life of cutting tool. As indicated in the Fig.4(a,b) the tool life achieved under highest cutting speed with both the feed is less than two minutes. Also at other two speed used the tool life is nearly two minutes.

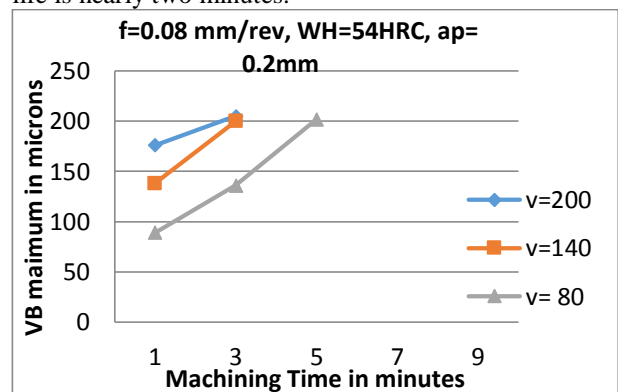


Fig.4(a) Progression of tool life at f=.08mm/rev, WH=54HRC on different cutting speeds

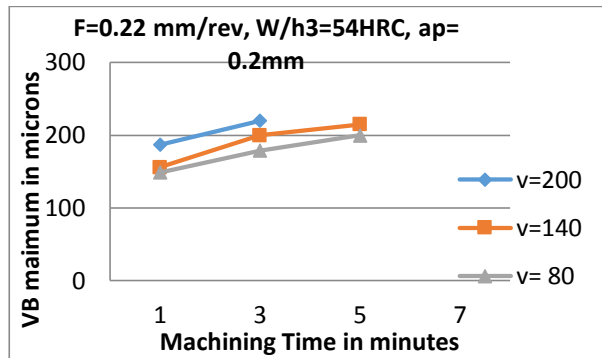


Fig.4(b) Progression of tool life at f=.22mm/rev, WH=54HRc on different cutting speeds.

Under all cutting speed and hardness range used there is marginal difference between the tool life achieved at f=.08mm/rev and f=.15mm/rev, while the significant difference in tool life was observed at highest feed. The tool life is low at highest feed selected. So the study reveals that the tool life of coated carbide tools is significantly affected by work piece hardness, followed by cutting speed and then feed.

**B. Tool Wear Mechanism**

As shown in Fig. 5, both flank wear and crater wear were observed for both the inserts tested under all cutting conditions. The tool wear zone occurred mostly near the tool nose radius, as depth of cut selected was quite low in comparison to the nose radius of the tool [4,6]. Both crater wear and flank wear near the nose of the tool occurred during the whole machining study with both the inserts on all types of surfaces.



Fig.5 The cutting insert after 3minutes of machining at v=80m/min,f=.08mm/rev and W.H.=40HRc.

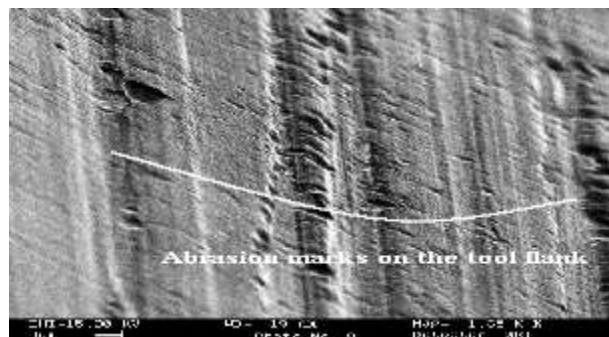


Fig.6 The cutting insert after 2minutes of machining at v=140m/min,f=.22mm/rev and W.H.=47HRc.



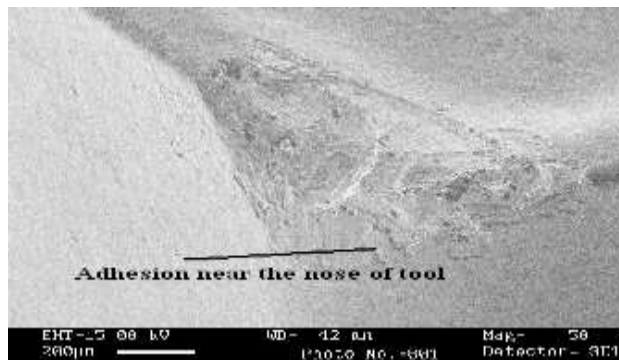
Fig.7 Edge Chipping of insert at v=200m/min, f=.22mm/rev and W.H.=54HRc

As shown in Figs 6 and 7, during the turning of workpiece hardness 47 HRc and 54 HRc the with carbide inserts, particularly at higher cutting speed (200 m/min), significant plastic deformation, chipping and breakage of cutting edge was observed. This kind of rapid tool wear with chipping/fracture was due to the high temperature generated and high mechanical loading on the tool edge during cutting. Failure of the tool edge started with propagation of cracks at higher speed [6,10].



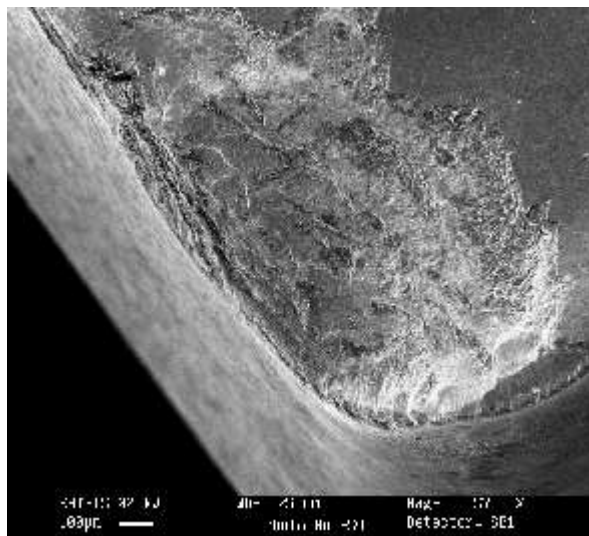
**Fig.8** The cutting insert after 2minutes of machining at  $v=80\text{m/min}$ ,  $f=.15\text{mm/rev}$  and  $W.H.=47\text{HRc}$

During turning at 80 m/ min cutting speed, abrasive marks were observed on the flank face as shown in Fig. 8, which occurred due to rubbing of hard carbides in the workpiece material on the tool edge [4, 6].



**Fig.9** The cutting insert after 3minutes of machining at  $v=140\text{m/min}$ ,  $f=.15\text{mm/rev}$  and  $W.H.=47\text{HRc}$

As shown in Fig.9, adhesion followed by plastic deformation was observed at 140 m/min cutting speeds during turning of the continuous surface. Due to increase in the cutting speed, the temperature at the work tool interface increased, which promoted adhesion wear [11,12]



**Fig.10** The cutting insert after 1minutes of machining at  $v=200\text{m/min}$ ,  $f=.22\text{mm/rev}$  and  $W.H.=54\text{HRc}$

Significant crater wear was also observed in particular at highest cutting speed, this is mainly due to removal of wear resistant coating from the surface [10]. The main wear mechanism involved with carbide inserts was abrasion and adhesion followed by plastic deformation at low to medium speed. On the other hand, rapid tool

wear with chipping/breakage of the tool edge was observed at higher cutting speeds, which led to the end of tool life.

### Conclusions

The life of the carbide tool was sensitive to both cutting speed and degree of work piece hardness. At highest degree of workpiece hardness, the tool life achieved under all circumstances was very short. However, coated carbide can become economical alternative to costly CBN at low and medium range of cutting speed, which was in this study as 80m/min and 140m/min and particular range of workpiece hardness that is in this case below 54HRc. With the carbide tool, abrasion and adhesion followed by plastic deformation were the main types of wear at low and medium cutting speeds, while chipping and breakage of tool edges were observed at higher cutting speeds.

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