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Wear mechanism and optimum parameters for finish hard turning using pvd coated carbide

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ABSTRACT

Surface roughness plays an important role throughout product life cycle. In present scenario, cylindrical grinding and centre-less grinding machines are used to achieve desired surface roughness value on hardened round steel bar. Now a day's Polycrystalline Cubic Boron Nitride (PCBN) and ceramic tools are explicitly used for finish hard turning. These tools have certain drawbacks like, PCBN inserts are inflexible for complex tool geometries and its prohibitive cost, ceramic tools are inappropriate for finished hard turning due to its blunt cutting edge. Various researchers focused on tool life, wear mechanism of coated or uncoated PCBN, carbide and ceramic tools. But very less focus is made on comparison of coated carbide tools. In present work four different types of physical vapor deposition (PVD) coatings viz. AlCrN based / AlTiN based / AlCrN are compared for optimum parameters viz. cutting speed, feed, depth of cut etc. on the basis of wear mechanism and surface roughness obtained. As the chip depth produced especially in finish hard turning process is very low, wear on the tool mostly occurs in the nose area. Hence behavior of different coatings is studied during finish hard turning of hardened EN-24. Further study on the coated tools is made to conclude optimum parameters for selected coatings. We attempted to show the damage mechanisms that occur in cutting tools used in experimental tests conducted under similar cutting conditions. The most commonly encountered types of damage the in hard turning process are flank wear and crater wear, chipping, plastic lowering of cutting edge and built up edge.

Keywords— **Cutting Parameters, Cutting tools, Finish Hard Turning, PVD coatings, Wear mechanism.**

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I. INTRODUCTION

Hard materials are very often used in mechanical industries, e.g. in manufacturing of cutting tools, forming tools or dies and moulds. So for the machining of these types of components, productively and competitively, we must focus to reduce machining cost and increase the quality of machining. The factors i.e. material of cutting tool, tool geometry, micro-geometry or thin film of coating are affecting on the durability and cutting ability of the cutting tool. So to achieve high productivity and economic production of such components, it is necessary to focus on all these factors.

The cutting parameters directly affects on the total manufacturing cost per component. So the cutting parameters i.e. cutting speed, feed and depth of cut selected for machining should be optimum for economical productivity. Selection of cutting tool and its parameters at the process planning level is still based on conservative cutting condition mentioned in handbook and on the skill & experience of machine tool operators, which is not very scientific approach may results in reduced productivity and sub-optimal use of machining capability.

Application of coating provides a potent means of improving wear resistance, reducing friction. Also it causes decrease of cutting forces and surface quality better. The thickness of this coating measures to few microns ranging from 1µm to 4 µm. The thin coating causes increase of tool life by 15 – 20 %. The thin film of coating materials applied on cutting tools achieves concerning properties e.g. hardness, friction toughness, temperature characteristics which none of the material can deliver alone. Two most common methods used for coatings are, CVD (Chemical Vapor Deposition) PVD (Physical Vapor Deposition). These coating offers good heat removal from tool- workpiece interface, offers lubricating property and reduces the thermal impact on the substrate. These coatings are provided with monolayer or multilayer.

Finish hard turning is the process of turning hardened ferrous material with a hardness value more than 45HRC in order to obtain finished work pieces directly from hardened parts. Tool wear is one of the most important topic in cutting field. Its interest is due to the influence of tool wear on surface integrity of the final parts and on tool life, and, consequently, on the substitution policies and production costs. Finish hard turning is a turning process which is applied on high resistance alloy steels to obtain surface roughness values that are close to those obtained in grinding operations (R ~ 0.1µm). The work-piece materials involved include various a hardened alloy steels, carburizing steel, tool steels, case-hardened steels, Ni based super alloys, HRSA (heat resistant super alloy), Hastelloy, nitrided iron, hard-chrome-coated steels and heat-treated powder metallurgical parts.

Finish hard turning has experienced significant growth due to the need for continuously improving productivity and decreasing the processing cost. It is potential alternative to conventional mechanical grinding. As the high hardness of work piece is involved in finish hard machining, high toughness and wear resistance for the tools are required. Also due to the high hardness of work pieces, large cutting forces and high temperature at the tool-work piece interface impose requirements for tool rigidity and tool wear resistance. It is estimated that 15% of manufacturing costs of a component are associated with cutting fluid costs.

PCBN (Polycrystalline Cubic Boron Nitride) tools are used for hard machining, due to its high hardness, high wear resistance and high thermal stability. The inflexibility of fabricating PCBN inserts with complex tool geometries and the prohibitive cost of a PCBN inserts are some of the concern for hard machining. Ceramic tools are also has a potential of hard machining, but they are not as tough as coated WC-Co inserts. They are normally used for rough hard machining due to their blunt cutting edge. The blunt edge of ceramic tool leads significantly high cutting force and less desirable surface finish.

Therefore, a solution is required to reduce the specific tool cost without degrading the tool performance and sacrificing productivity for further developments in hard machining. In this paper, three different coatings are compared in terms of optimum parameters and wear mechanisms during the turning of EN-24 hardened alloy steel with hardness 48±2 HRC. For the cutting tools with same geometry and same carbide grade, different thin films of coatings are used to find the optimum parameters and wear mechanisms. The main aim is to achieve required surface finish close to that obtained in grinding operations (R ~ 0.1µm). The results of this paper are further used for the research and development of cutting tools for finish hard machining.

II. RELATED WORK

Kadirgama et.al. tested the tool behavior, in terms of wear and tool life after machining of Hastelloy C-22HS on VMC (vertical machining centre) by using four different cutting tool materials under wet condition– namely, Physical Vapour Deposition (PVD) coated with TiAlN; TiN/TiCN/TiN; Chemical Vapour Deposition(CVD) coated with TiN/TiCN/Al2O3; and TiN/TiCN/TiN. The influence of different coating on this behavior was investigated. Flank wear, chipping, notching, plastic lowering at cutting edge, catastrophic and wear at nose were found to be the predominant tool failure for the four types of cutting tools, specially with CVD tools.[1]

More et.al. compared the results of compositely coated(cBN plus TiN) carbide insert with PCBN insert to examine the tool wear and machining performance in turning AISI 4340 hardened steel under similar cutting conditions. The crater wear of the cBN–TiN coated inserts is less than that of the PCBN inserts because of the lubricity of TiN in composite coating. The tool life of compositely coated carbide insert found 18-20 min per cutting edge whereas PCBN tool produced the tool life of 32 min. Also its observed that total machining cost per component is less for cBN –Tin coated carbide insert as compared to PCBN insert. [2]

Thakur et.al. experimented the effect of cutting speed and chemical vapour deposition (CVD) multilayer coating on machined surface integrity of Inconel 825 during dry turning, with particular focus on measurement of sub-surface hardness and white layers. Experimental result shows that that increase in cutting speed increased white layer thickness after machining. At lower cutting speed CVD coated cemented carbide insert are compared with uncoated inserts resulted in decrease in white layer thickness. The work hardening tendency in the surface region after turning with multilayer coated tool found reducing. [3]

Nexhat Qehaja et.al. examined the effect of machining parameters i.e. feed rate, tool geometry, nose radius, and machining time, on the roughness of surface produced in dry turning with coated tungsten carbide inserts. C62D cold rolled steel was used for experimentation. The results indicate that the parameters like feed rate, nose radius and cutting time are the majorly affecting surface roughness value. Out of feed rate, nose radius and cutting time, effect of feed rate on surface roughness is more significant.[4]

Varaprasad. Bh et.al. experimented Al_2 O_3 /TiC mixed ceramic tool with corner radius 0.8 mm for turning of AISI D3 hardened steel and observed the flank wear. He concluded that, depth of cut is a significant parameter for tool flank wear. The speed and feed rate have little influence on the total variation.[5]

Literature review has indicated that considerable of research effort have been devoted to the study of tool life and wear mechanism in hard turning process. So far, the performance of PVD coated tungsten carbide tools has not been completely studied in the finish hard turning process. It is obviously known that coating can improve wear resistance and increase tool life. Therefore, this paper focuses on the performance of PVD coated carbide cutting tools, coated with AlTiN based/ AlCrN Based/ AlCrN in terms of cutting parameters and wear mechanisms. In the present study, an attempt has been made to investigate the effect of process parameters (cutting speed, feed rate and depth of cut) on the tool wear in finish hard turning of EN-24 steel hardened at 47-49 HRC with coated carbide tool.

III. PROPOSED WORK

3.1 Workpiece Material

Fig.1 EN-24 workpiece

The workpiece material used in this study was thoroughly hardened EN-24 steel (~50 HRC), which typically has a chemical composition as shown in table I.

TABLE I. CHEMICAL COMPOSITION OF EN-24 STEEL

Elem ents	C	M n	Si	S	P	N i	Cr	Mo
%	0.4 29	0.5 75	0.2 35	0.0 12	0.0 13	1. 3 6	1.0 9	0.2 6

The solid bar has a diameter of 40 mm and a length of 310 mm. A circular disc of diameter 40 x 10 mm length is obtained from stock material to examine chemical composition. The pieces of dia. 40 x 100 mm is cut from bar of 300mm using power hack saw machine. In order to ensure consistency of hardness, a light cut (0.25 mm radial) on outer surface of the test bars on conventional lathe machine along with the facing operation prior to the hardening process. Then the test bars were heat treated as follows, furnace used-electrically heated forced air circulating pit type drip Feed gas carburising furnace. Hardened at 860^0C for 3 Hrs. Quenching in Oil for 30-40Min.(as quench hardness is 58-60 HRC) General Tempering at 220^0C for 3 Hrs. Final Tempering at 450^0C for 2 Hrs.

Hardness of the bars is measured by using micro hardness test at test load of 1.0 kgf. to ensure the through and uniform hardness of teat bars. Results found as shown in table II,

TABLE II MICRO HARDNESS TEST RESULT AFTER HARDENING,

S. N.	Distance from surface in mm	Hardness Conversion in HV	Hardness Conversion in HRC
1	0.05	490.0	48.4
2	1.00	500.0	49.1
3	2.00	497.0	49.0
4	Core	497.0	49.0

3.2 Cutting Tool and Tool Holder

Fig. 2 Tungsten Carbide tool

The tungsten carbide is an inorganic chemical compound containing equal percentage of tungsten and carbon atoms. Tungsten carbide is often simply called carbide. Basically carbide is a fine gray powder, but for making tools and other components it is pressed and formed into different shapes. Approximately carbide is three times stiffer than steel. For this work a Kennametal make tungsten carbide inserts with designation CNMG 090304 FF KC5010 has been chosen. This grade of carbide is PVD coated and highly wear resistant which is used for universal machining applications. The chip breaker used for this inserts is FF which is recommended for fine finishing having nose radius = 0.4 mm, profile angle = 20^0 (positive), and normal clearance angle = 0^0, is used for the experimentation. The inserts were mounted on a left-hand tool holder, PCLNL 1616 H09, having following data, Insert clamping structure = Lever lock type, Cutting angle = 95^0, Negative clearance angle= 6^0, Hand of tool =

Left, Shank height and width = 16mm, Tool shank length= 100mm, Cutting edge length= 9 mm.[6]

Deposition of coating decrease the diffusion coefficient and the solubility coefficient of WC cutting tools, this results in a much lower solubility in work piece than the uncoated tools. It is possible to cut the material in dry condition with deposition of coating, which saves the estimated cost of cutting fluids by 15% of manufacturing cost of a component. Three different PVD coatings (AlTiN based/AlCrN/AlCrN based) were selected, in accordance with rough indication expressed in technical literature and the suggestions obtained from coating producers and application experts. Similar geometry and grade of tool is used with other coatings so that the machining results could be compared under similar cutting conditions. The different properties of coatings are as shown in table III.

TABLE III PROPERTIES OF COATINGS USED FOR EXPERIMENT.

Coating Material	**AlTiN based**	**AlCrN**	**AlCrN-based**
Microhardness (HV 0.05)	3000	3200	3300
Coefficient of friction against steel (dry)	0.35	0.35	0.35 – 0.40
Coating Thickness (µm)	2-3	2-3	2-3
Residual compressive stress(GPa)	-3.0	-3.0	-3.0
Max service temperature(^{0}C)	1000	1100	>1100
Coating temperature (^{0}C)	<600	<500	<600
Coating colour	Gray	Bright gray	Blue gray
Coating structure	Multi layer	Monola yer	Multi layer

The CNC machine tool used in this experimentation is a MTAB MAXTURN with Fanuc Power Oi- Mate control. This machine is chosen, as it is capable of cutting resistant materials. This machine has slant bed, 8 station programmable turret and manual 125 mm self centering three jaw chuck. This machine has following specifications,

Chuck size=125mm, Maximum turning diameter= 130 mm, Maximum turning length=100 mm, Motor rated output= 3.7 kW, Accuracy of positioning of axes = 0.01mm, Repeatability= ±0.005 mm and roundness of the standard test piece= 0.01 mm.[7]

Fig.3 Machining on MTAB CNC Machine

3.3. Machining Experiments

1.3.1. Selection of Machining Parameters

There are three main process parameters related to turning process i.e. cutting speed, feed rate and depth of cut. In this work results are obtained by varying one parameter and keeping other two constant.

Table IV shows that change in surface finish by varying depth of cut. In this case, depth of is taken as 0.15 with the increment of 0.05 mm and spindle speed and feed are 1000 rpm and 0.15mm/rev. respectively.

TABLE IV RESULTS AGAINST VARYING DEPTH OF CUT.

S N	**Speed RPM**	**Feed Rate mm/rev**	**DoC (mm)**	**Dia. before machining (mm)**	**Dia. after machining (mm)**	**Surface finish (µm)**
1	1000	0.15	0.10	40.0	39.8	1.21
2	1000	0.15	0.15	39.80	39.50	1.35
3	1000	0.15	0.20	39.50	39.10	1.01
4	1000	0.15	0.25	39.10	38.60	1.22
5	1000	0.15	0.30	38.60	38.00	1.93
6	1000	0.15	0.35	38.00	37.30	2.12
7	1000	0.15	0.40	37.30	36.50	2.62

Table V shows that change in surface finish by varying feed rate. In this case, feed rate is taken as 0.15 mm/rev. with the increment of 0.02 mm/rev. and spindle speed and depth of cut are 1000 rpm and 0.3mm respectively.

TABLE V RESULTS AGAINST VARYING FEED RATE.

Table VI shows that change in surface finish by varying spindle speed. In this case, spindle is taken as 1000 rpm with the increment of 100 rpm and feed rate and depth of cut are 0.15 mm/rev and 0.3mm respectively.

TABLE VI RESULTS AGAINST VARYING SPINDLE SPEED.

S N	**Speed RPM**	**Feed Rate mm/rev**	**DoC (mm)**	**Dia. before machining (mm)**	**Dia. after machining (mm)**	**Surface finish (μm)**
1	800	0.15	0.3	32.30	31.70	2.23
2	900	0.15	0.3	31.70	31.10	1.94
3	1000	0.15	0.3	31.10	30.50	1.56
4	1100	0.15	0.3	30.50	29.90	1.18
5	1200	0.15	0.3	29.90	29.30	0.97
6	1300	0.15	0.3	29.30	28.70	1.04
7	1400	0.15	0.3	28.70	28.1	1.15

S N	**Speed RPM**	**Feed Rate mm/rev**	**DoC (mm)**	**Dia. before machining (mm)**	**Dia. after machining (mm)**	**Surface finish (μm)**
1	1000	0.1	0.3	36.50	35.90	1.71
2	1000	0.12	0.3	35.90	35.30	1.56
3	1000	0.14	0.3	35.30	34.70	1.34
4	1000	0.16	0.3	34.70	34.10	1.25
5	1000	0.18	0.3	34.10	33.50	1.12
6	1000	0.20	0.3	33.50	32.90	1.42
7	1000	0.22	0.3	32.90	32.30	1.68

IV. CONCLUSIONS

In this work EN-24 steel is taken as a work material and tungsten carbide as tool material. By varying the different parameters like depth of cut, speed and feed at different conditions surface finish, was calculated. The results showed that the tool life is decreasing as the cutting speed increases. The optimum process parameters obtained from experimentation are shown in table VII.

TABLE VII OPTIMUM PROCESS PARAMETERS

S.N.	DoC (mm)	Speed (rpm)	Feed (mm/rev)	Surface finish(μm)
1	0.20	1000	0.15	1.01
2	0.30	1000	0.18	1.12
3	0.30	1200	0.15	0.97

From above experimental results the optimum parameters found are DoC=0.20-0.30 mm, Spindle speed= 1000-1200 rpm and feed rate= 0.15-0.20 mm/rev.

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