



Study & Performance of Coated Cutting Tool

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Abstract: The use of coated cutting tools in the machining of various materials now represents state of the art technology. Developments in coating equipment and processes now enable us to produce a wide range of different hard nitride, carbide and oxide films and to deposit them on various tool substrates as monolayer, multilayer, or composite coatings. A total coating thickness between 3-10 μm is generally appropriate. The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. This paper reports a case study on the AISI 4340 alloy steel cylindrical work pieces of 50 mm diameter hardened steel of 45HRC with coated tungsten carbide tool and gives the detail about the performance of coated cutting tool and their parameters at different cutting conditions.

Keywords: Coatings; Cutting tools; Tool wear; Cutting parameters; Wear resistance.

I. Introduction

Cutting tools are subjected to high stresses in modern machining practice like dry, high-speed or high-performance machining. The development of new processes demands adapted cutting tools. An ideal cutting material combines high hardness with good toughness and chemical stability. In particular, hardness and toughness represent opposing properties and there is no single cutting material, which achieves all three conditions simultaneously. In order to merge the mentioned characteristics, wear resistant coatings with tough substrate materials are combined. The research of a correlation between the results of the most common laboratory tests and the cutting performances of the coatings is of great interest not only for the cutting tool makers, but also for the end users, since this could lead to the formulation of a test protocol to forecast cutting tool life. Furthermore, in the case of the nanocomposite coatings, for which the cutting tests can be very expensive due to their high cutting life, a set of laboratory tests can be cheaper than an extensive experimental plan of cutting tests. Surface engineering recently became a major way to improve cutting tools wear resistance and productivity. There are several ways of cutting tool surface engineering evolution. First one (and most commonly used) is a development of advanced PVD coating compositions. But application of an advanced coating for HSS tools cannot guarantee the optimal result without the special substrate surface treatment prior to the hard coating deposition [1] [2].

II. Theory of Metal Cutting

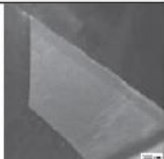
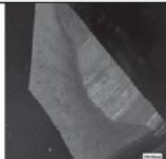
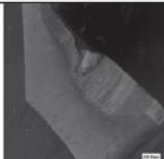
Metal cutting process forms the basis of the engineering industry and is involved either directly or indirectly in the manufacture of nearly every product of our modern civilization. The cutting tool is one of the important elements in realizing the full potential out of any metal cutting operation. Over the years the demands of economic competition have motivated a lot of research in the field of metal cutting leading to the evolution of new tool materials of remarkable performance and vast potential for an impressive increase in productivity. As manufacturers continually seek and apply new materials for products that are lighter and stronger and therefore more efficient employing that cutting tools must be so developed that can machine new materials at the highest possible productivity. The main properties which any cutting material must possess in order to carry out its function are: Hardness, Hot strength, sufficient toughness etc. In general, increasing hardness brings with it a reduction in toughness and so those materials in the higher hardness region of the list will fail by breakage if used for heavy cuts, particularly with work pieces which have holes or slots in them which give rise to interruption in the cut [3].

III. Tool Wear

Cutting tools are mostly assessed in terms of wear studies during and after the manufacturing processes. The prediction and control of wear is one of the most essential problems emerging in the design of cutting operations. A useful definition for a worn out tool is: "A tool is considered to be worn out when the replacement cost is less than the cost for not replacing the tool". Tool failure is said to occur when the tool no longer performs the desired function whereas total failure (ultimate failure) is defined as the complete removal of the cutting edge, a condition

obtaining when catastrophic failure occurs. Therefore, in machining operations, tools are considered to be worn out and are changed long before total failures to avoid incurring high costs associated with such catastrophic failures. The tool may experience repeated impact loads during interrupted cuts, and the work piece chips may chemically interact with the tool materials. The useful life of a cutting tool may be limited by a variety of wear processes such as crater wear, flank wear or abrasive wear, built up edge, notching and nose wear [4].

Fig. 1: Machining with uncoated tool.

Tool Type	Before Machining	Machining after 5 min	Machining after 25 min
Uncoated			

IV. Coatings

Machining efficiency is improved by reducing the machining time with high speed machining. But the softening temperature and the chemical stability of the tool material limits the cutting speed. 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. 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 [5][6].

Carbide substrates are used because of their

- Higher Productivity by high speed machining
- Improved toughness and crack resistance by optimal dispersion of hard particles.
- Improved plastic deformation resistance and welding resistance for high cutting speed operations.

The effects of coatings are

1. Reduction in friction
2. Reduction in generated heat
3. Reduction in cutting forces.
4. Reduction in the diffusion between the chip and the surface of the tool, especially at higher speeds (the coating acts as a diffusion barrier).
5. Prevention of galling, especially at lower cutting speeds.

Methods of Coating:

A. Chemical Vapour Deposition(CVD)

Chemical Vapor Deposition (CVD) is an atmosphere controlled process conducted at elevated temperatures ($\sim 1925^\circ F$) in a CVD reactor. During this process, thin-film coatings are formed as the result of reactions between various gaseous phases and the heated surface of substrates within the CVD reactor. As different gases are transported through the reactor, distinct coating layers are formed on the tooling substrate. CVD method deposits thin films on the cutting tools through various chemical reactions. CVD coated cemented carbides have been a huge success since their introduction in the late 1960's. Since then, chemical vapour deposition technologies have advanced from single layer to multi-layer versions combining TiN, TiCN, TiC and Al_2O_3 . Modern CVD coatings combine high temperature and medium temperature processes in complex cycles that produce excellent wear resistant coatings with a total thickness of 4-20 μm . However, the high deposition temperature ($950-1059^\circ C$) during CVD results in diffusion of chemical elements from the carbide substrate to the coating during growth. The main effect is to make brittle coating edge. In addition, the chemistry of the CVD process results in more rapid growth at the cutting edge resulting in an even coating thickness. Therefore, there was a strong driving force to find coatings that could be deposited at lower temperatures in order to allow tools with sharper edges to be coated without any embrittlement effect. The solution is PVD where deposition temperature can be kept at around $500^\circ C$ [3].

B. Physical Vapour Deposition (PVD)

Physical vapor deposition (PVD) describes a variety of vacuum deposition methods used to deposit thin films by the condensation of a vaporized form of the desired film material onto various workpiece surfaces. PVD method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation. PVD coatings, with deposition temperatures of $400-600^\circ C$, are gaining greater acceptance in the market place. Over the last decade, they have been successfully applied to carbide metal cutting inserts. They offer performance advantage in applications involving interrupted cuts, those requiring sharp edges, as well as finishing and other applications. Depending on the intended application, different PVD technologies such as electron beam

evaporation, sputtering and arc evaporation are used. The metal cutting performance of PVD coated tools depend strongly on the composition, microstructure, internal stresses and adhesion of the coating to the substrate as well as the substrate composition and tool geometry. PVD process chain includes pre-PVD processes and post-PVD processes. Pre-treatment processes such as plasma etching and chemical etching influence adhesion, grain growth, stress at substrate surface and coating structure, whereas post-PVD processes influence smoothness of coating surface and better chip flow. PVD coatings attribute excellent cutting performance to cemented carbide inserts. The reason that PVD has more and more taken over with regards to deposition of many coatings is the advantages that lower coating temperatures give with regard to micro-toughness [3]. It is more environmentally friendly than traditional coating processes such as electroplating and painting.

V. Types of Coatings

A. Single layer coating

The first coating was a single layer of TiC. 10 to 12 micrometers thick, which was deposited by a process known as chemical vapour deposition (CVD) onto a substrate of hard metal. During the deposition process some carbon was taken up from the surface of the hard metal as part of coating and this changed the carbon balance at the junction of the coating and the hard metal substrate. This lowering of the carbon balance caused the formation of a brittle compound at the interface between the coating and the substrate and made early coated indexable inserts sensitive to chipping of cutting edge. The next development was to put down a coating of TiN which prevented any decarburizing of the hard metal substrate but the coating which is gold in colour, did not adhere well to the hard metal base. TiN is an even better diffusion barrier than TiC but TiC has better abrasion resistance [3].

B. Multi-layer coating

Although single-layer coatings are finding a range of applications in many sectors of engineering, there are an increasing number of applications where the properties of a single material are not sufficient. One way to surmount this problem is to use a multilayer coating that combines the attractive properties of several materials, each chosen to solve a problem in the application. Multi-layer coatings can consist of as many as eight layers within a total thickness of 10 micrometers or less. Simple examples of this include the use of interfacial bonding layers to promote adhesion, or thin inert coatings on top of wear-resistant layers to reduce the corrosion of cutting tools. There is, however, mounting evidence that the multilayer structure produced when many alternating layers of two materials are deposited can lead to improvements in performance over a mixed coating even if the two materials do not have specific functional requirements in the intended application [3].

VI. Common Coatings

Titanium Nitride (TiN):

General purpose PVD coating that increases hardness and has a high oxidation temperature. This coating works great while cutting or forming with HSS tooling.

Titanium Carbo-Nitride (TiCN):

The addition of carbon adds more hardness and better surface lubricity.

Titanium Aluminum Nitride (TiAlN or AlTiN):

A formed layer of aluminum oxide gives this tool better life in high heat applications. This coating is primarily selected for carbide tooling where little to no coolant is being used. AlTiN offers a higher surface hardness than that of TiAlN, along with different percentages of aluminum and titanium. It is another viable option in the world of HSM.

Diamond:

A CVD process that offers the highest performance available in non-ferrous materials. Ideal for cutting graphite, MMC (Metal Matrix Composites), high silicon aluminum and many other abrasive materials. Coatings for hard milling, tapping and drilling all vary and are application-specific. Also available are multi-layer coatings that chip to the next layer instead of the tooling substrate, providing a further increase in tool life.

Chromium Nitride (CrN):

The anti-seizure properties of this coating make it preferred in situations where BUE is common. HSS or carbide cutting and forming tools will be seen with this almost invisible coating [3].

VII. Parameters Used in Cutting Tool

Table 1: Various Parameters/Properties of Coated & Uncoated Tool

Sr. No.	Properties/Parameters	Uncoated tool	Coated tool
1	Surface roughness	Satisfactory	Good with same cutting conditions as of uncoated tool
2	Chemical stability	Poor	Improved results with same cutting conditions as of uncoated tool
3	Anti-welding & anti-diffusivity	Satisfactory	Improved results with same cutting conditions as of uncoated tool
4	Thermal conductivity	Poor	Good with same cutting conditions as of uncoated tool
5	Thermal expansion coefficient	Medium	Low with same cutting conditions as of uncoated tool
6	High strength and wear resistant	Satisfactory	Improved results with same cutting conditions as of uncoated tool

Sr. No.	Properties/Parameters	Uncoated tool	Coated tool
7	Resistance to thermal and mechanical shock	Poor	Improved results with same cutting conditions as of uncoated tool
8	Resistance to diffusion	Satisfactory	Improved results with same cutting conditions as of uncoated tool
9	High resistance to the brittle fracture	Poor	Improved results with same cutting conditions as of uncoated tool
10	Cost	High	Low
11	Low Cost and ease of fabrication	Satisfactory	Improved results with same cutting conditions as of uncoated tool
12	Surface lubricity	Less	High & scope of improvement
13	Anti-seizure	Low in this case	High in this case

VIII. Performance of Coated Cutting Tool in Machining Hardened Steel

In hard turning the material is harder, specific cutting forces are larger than in conventional turning, and thus the engagement between cutting tools and the work piece must be limited. In hard turning small cutting depths required, cutting takes place on the nose radius of cutting tools, and the tools are typically prepared with chamfered or honed edges to provide a stronger edge geometry that is less prone to premature fracture. The large negative rake angles yield increased cutting forces compared to machining with positive rake tools, and also induce larger compressive loads on the machined surface. Higher temperatures are also generated in the cutting zone, and because cutting is typically done without coolant, hard turned surfaces can exhibit thermal damage in the form of micro structural changes and tensile residual stresses [7].

Experimentation:

This case deals with the study of the performance of coated tools in machining hardened steel under dry conditions. This involve machining of AISI 4340 hardened steel using coated tungsten carbide tool by considering full factorial experiments. In the present case the experiments were conducted on AISI 4340 alloy steel cylindrical work pieces of 50 mm diameter hardened steel of 45HRC with coated tungsten carbide tool at different cutting conditions. The objective of this study is on the effect of the cutting conditions such as cutting velocity, feed, and depth of cut on the surface finish in machining AISI 4340 hardened steel. Machining of hardened steels has become an important manufacturing process, particularly in the automotive and bearing industries [7].

Table 2: Machining parameters & their levels

Machining Parameters	Symbol	Levels		
		Level 1	Level 2	Level 3
Cutting Velocity (m/min)	v	60	80	100
Feed Rate (mm/rev.)	f	0.2	0.4	0.63
Depth of Cut (mm)	d	0.25	0.5	0.75

The cutting parameters selected for the present investigation is cutting velocity (v), feed (f) and depth of cut (d) as shown in Table 2. In machining of parts, surface quality is one of the most specified customer requirements where major indication of surface quality on machined parts is surface roughness. Surface roughness is mainly a result of process parameters such as tool geometry and cutting conditions (feed rate, cutting speed, depth of cut, etc.). The surface roughness was measured by using Mitutoyo surface roughness tester (SJ-201 P) stylus type [7].

Table 3: The measured surface roughness at different cutting conditions

Sr. No.	Machining Parameters			Surface Roughness Ra (µm)
	Cutting Velocity v (m/min)	Depth of Cut d (mm)	Feed Rate F (mm/rev.)	
1.	60	0.25	0.2	0.46
2.	60	0.25	0.4	2.27
3.	60	0.25	0.63	2.34
4.	60	0.5	0.2	0.48
5.	60	0.5	0.4	2.17
6.	60	0.5	0.63	3.53
7.	60	0.75	0.2	1.93
8.	60	0.75	0.4	2.53
9.	60	0.75	0.63	3.62
10.	80	0.25	0.2	0.54
11.	80	0.25	0.4	2.56
12.	80	0.25	0.63	2.03
13.	80	0.5	0.2	1.86
14.	80	0.5	0.4	3.02
15.	80	0.5	0.63	3.54
16.	80	0.75	0.2	2.63
17.	80	0.75	0.4	4.01
18.	80	0.75	0.63	5.22
19.	100	0.25	0.2	0.18
20.	100	0.25	0.4	1.39
21.	100	0.25	0.63	2.74
22.	100	0.5	0.2	0.46

Sr. No.	Machining Parameters			Surface Roughness Ra (μm)
	Cutting Velocity v (m/min)	Depth of Cut d (mm)	Feed Rate F (mm/rev.)	
23.	100	0.5	0.4	2.33
24.	100	0.5	0.63	3.74
25.	100	0.75	0.2	1.59
26.	100	0.75	0.4	3.53
27.	100	0.75	0.63	4.44

Fig. 2: The variation is surface roughness with feed rate at constant-

- i) Cutting velocity (60m/min) at different depth of cuts.(Fig.a)
- ii) Cutting velocity (100m/min) at different depth of cuts.(Fig.b)
- iii) Depth of cut (0.25mm) at different feed (d=0.25).(Fig.c)

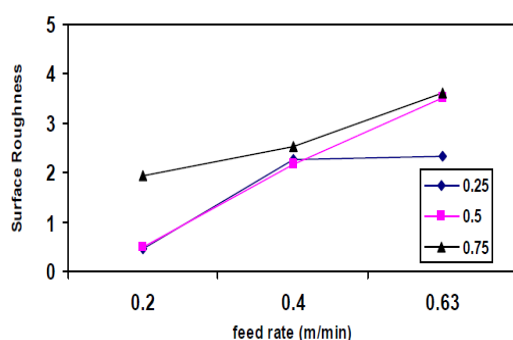


Fig. (a)

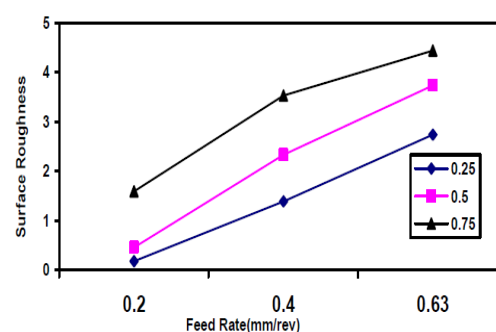


Fig. (b)

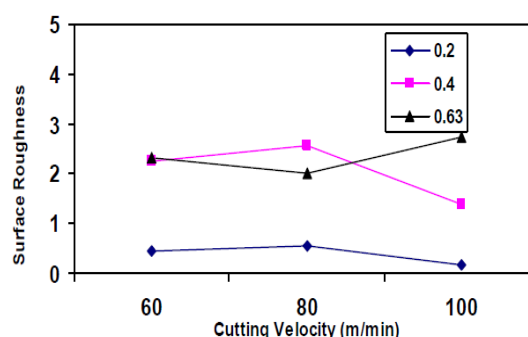


Fig. (c)

IX. Discussion & Result

The variation is surface roughness with feed rate at constant cutting velocity (60 m/min) at different depth of cuts is shown in Fig.(a). Fig.(b) shows the variation is surface roughness with feed rate at constant cutting velocity of 100 m/min at different depth of cuts. The variation is surface roughness with feed rate at constant depth of cut (0.25 mm) at different feed is shown in Fig.(c) The experimental results show at some selected condition the surface roughness is observed to be poor. The experimental result shows with increasing the feed rate the surface roughness is increasing. From the selected conditions for feed rate of 0.63mm/rev the surface roughness is high when compared to other selected feeds. At constant feed the effect of cutting velocity on surface roughness is less as shown Fig.(c). In the present work the performance of coated tools in machining hardened steel under dry conditions is studied. The experimental results showed with increase in feed the surface roughness is observed is very poor. The effect of cutting velocity on surface roughness is relatively low when compared to feed rate. With increase in depth of cut the surface roughness is increased. Here experimental results shows by selecting the proper cutting parameters the coated tools are suitable to produce fine surface finished components.

X. Conclusion

This work considered some ways to improving cutting tool life by means of coating method. The performance of coated cutting tool is better than the conventional cutting tool. Tool coating improves properties of cutting tool such as surface roughness, Chemical stability, anti-welding and anti-diffusivity, thermal conductivity, Surface lubricity and anti-seizure. Coated tool also suitable for various cutting conditions such as cutting velocity, feed rate and depth of cut. Tungsten Carbide coated cutting tool cuts about 3 to 5 times faster than conventional cutting tools.

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