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INVESTIGATION OF PVD COATINGS FOR CUTTING TOOL APPLICATIONS

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ABSTRACT

Enhancement of wear resistance has been a major interest for the cutting tool industry for few decades. Hence this work emphasizes the influence of the TiN and AlCrN coatings deposited on high speed steel form tool using Physical vapor deposition (PVD) technique. The microstructural studies of the above coatings were analyzed using Scanning electron microscope (SEM). Surface finish was measured by surface roughness testing machine. Hardness measurements were performed using Vickers hardness test. In addition to the above, the influence of the above coatings on the machining performance of the high speed steel was also evaluated and compared with that of the uncoated material.

Key words: *PVD, HSS, SEM, Hardness and Wear test*

1. Introduction

In the field of mechanical and manufacturing engineering wide varieties of machines, equipments and tools are used. And with the passing time, advancement has been done on this machines and tools to increase the efficiency and the performance. As the modifications are done in the tools and machines, it increases machiniabilty, productivity and quality of the products.There are many tools used in the field of engineering such as high speed steel, carbide tipped tool-inserts, cemented carbide, diamond etc.The most widely and commonly used tool in the engineering field is high speed steel (HSS). There are many tools made of high speed steel. The HSS tools are the cheapest and reliable to machine.

While liquid nitriding is a surface modification technology, PVD coating involves the deposition of thin (2-10 microns; 0.0001”–0.0004”) films on the surface of tools and components. The PVD coating process can be divided into three stages:

Evaporation – Removal of material from the target, source or cathode.

Transportation – Travel of evaporated material from the source to the substrate.

Condensation – Nucleation and growth of the coating on the substrate surface.

Material is usually removed from the target surface either by sputtering or by an arc-discharge. The transportation step is through a plasma medium. Plasma is a collection of charged particles, whose constituents can be influenced by magnetic fields and tend to travel in straight lines or “line of sight” from source to substrate. Different characteristics are imparted to the plasma depending upon the technique used to generate it. A PVD coating is formed when plasma constituents and reactive gases combine on the substrate surface. Besides its specific chemical constituents and the architecture of the sub-layers, the properties of a PVD coating depend upon: ion energy; the degree of ionization of the metal ions; and mobility of the atoms condensing on the substrate surface.

There is a broad range of available PVD technologies – including conventional arc deposition and magnetron sputtering, coupled with technology enhancements that yield high deposition rates and thin films with high adhesion and diverse microstructures. HEF PVD coatings are deposited using three different technologies:

Lim (1997) in their paper titled “Crater wear of TiN coated high speed steel tool inserts” reports that the crater wear characteristics of TiN coated high speed steel (HSS) tool inserts during single point dry turning operations. Experimental data obtained from carefully executed single point dry turning tests as well as from the technical literature enabled the construction of wear maps showing the crater wear behavior of these tools over a wide range of machining conditions. The maps show that there is safety zones (defined by a range of feed rate and cutting speed) within which the rates of crater wear are the lowest. The concept of an overall wear damage map for TiN coated HSS tool inserts is discussed and such a map for this group of coated tools is presented for the first time.

Ian Birkb in his paper titled “ Performance of PVD coated high speed steel tools and the effect of

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deposited layers" explains that non-metallic inclusions in steel in relation with the formation of deposited layers PVD coated HSS tools.Non-metallic deposits on the rake face of high speed steel (HSS) tools have a considerable effect on tool life. It is known that for carbide cutting tools used to machine steels, deposited layers containing aluminum, silicon and calcium are a key factor in increasing tool life and cutting speeds. However, the existence of alumina has detrimental effects on tool life.

Munz and Wolf-Dieter in their paper titled "Titanium aluminum nitride films-A new alternative to TiN coatings" explains that TiAl films have been produced in various compositions by using the sputter ion plating process. Films sputtered reactively from a target with the composition of TiAl 50:50 at. % have been deposited with a composition of 27.5 at. % Ti, 28.9 at. % Al, and 43.6 at. % N. The crystal structure found was that of sodium chloride with a lattice parameter of 4.20 Å; the microhardness such films were found to be HV 2100–2300. The incorporation of Al into the nitride films improves the oxidation resistance as well as the cutting performances of TiAlN coated drills. TiN films start to oxidize at a temperature level of 550 °C, whereas TiAl coatings react with hot air at a temperature of 800 °C severely. TiAlN coated drills have been tested with two different steels and performed better by a factor $\gg$2 compared with TiN coated drills.

Frank H.W. Löffler in his paper "Systematic approach to improve the performance of PVD coatings for tool applications" reveals that for some years indexable tips coated by physical vapour deposition (PVD) have been tested regarding their performance characteristics. Beyond this there is great interest in PVD coatings for new applications in the field of tool technology. The variety of application conditions (principles) and the multitude of parameters complicate the establishment of PVD technologies in these fields. This paper describes a systematical approach which is useful for new developments of PVD-coated tools and has already been proven successful for various applications. Furthermore, a number of examples are presented to which this systematic approach has been applied. Besides applications in cut-machining operations, e.g. milling, drilling, turning and rasping, there are also tools applied within the areas of production die casting, forging, feeding or measuring, mostly working under extreme conditions (high temperature corrosion, thermal shock, adhesive wear and abrasion).

2. The Factors Affecting Tool Life

Cutting speed
Feed and depth of cut
Tool geometry
Tool material
Cutting fluid
Work material
Rigidity of work, tool and machine.

2. 1 Tables

Table 1: The Hardness and Roughness Value of the Uncoated HSS Tool

Hardness value @ 0.5 kg load	Roughness value Ra in (μm)
810.6 H.V	0.781
846.8 H.V	0.850
842.5 H.V	0.813
846.3 H.V	0.800

Table 2: The Hardness and Roughness Value of the Coated Tool

Hardness value @ 0.5 kg	Roughness value Ra (μm)
979.3 HV	0.229
979.3 HV	0.299
985.5 HV	0.198
990.4 HV	0.250

Table 3: Weight Loss for Un-Coated Tools

	Weight 1(g)	Weight 2(g)	Weight 3(g)
Initial	67.703	67.704	67.704
Trial 1	66.880	66.881	66.881
Trial 2	66.300	66.301	66.300
Trial 3	65.489	65.489	65.490

Table 4: Weight Loss for Coated Tools

	Weight 1(g)	Weight 2(g)	Weight 3(g)
Initial	67.160	67.161	67.161
Trial 1	66.999	66.998	66.998
Trial 2	66.850	66.851	66851
Trial 3	66.660	66.660	66.661

Table 5: Cost Analysis

Content	Cost (rupees)
Tool white bit (2 no's)	Rs. 250
Cost for physical vapour deposition coating for 1 tool	Rs. 380
The cost of test conducted to find thickness coating	Rs. 200
Test to find hardness value (both tools)	Rs. 700
To find roughness value (both tools)	Rs. 600
To find the weight of the tool (both tools)	Rs. 200

2.2 Figures

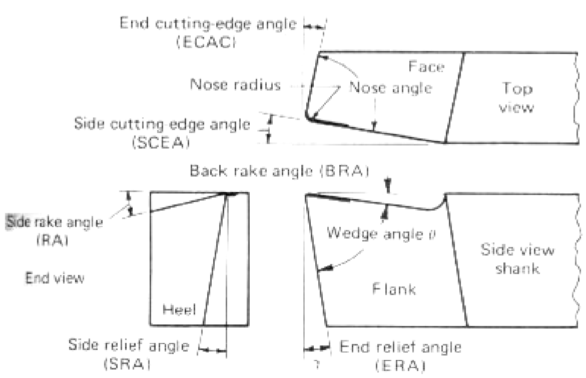

Fig. 1 Single Point Cutting Tool Nomenclature (10)

Fig. 2 Microscopic Images of the Cutting Tools.

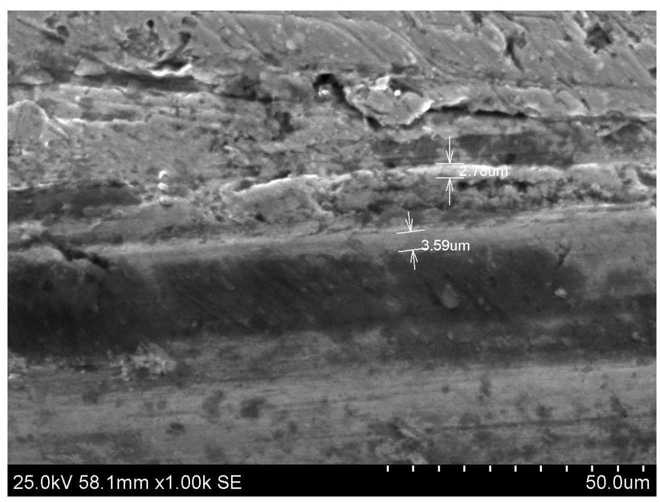

Fig. 3 SEM image of the bilayered coating

Cutting speed, $V = \frac{\pi D N}{1000}$ m/min

Time of tool failure $T = \sqrt[0.19]{\frac{257}{v \times f^{0.36} \times t^{0.08}}}$

Where,

D - Diameter of the work piece

N – R.P.M of the work piece

d – depth of cut in mm

f – feed mm/min

T – time of tool failure in min

L – tool life in 1mm3 of metal removal

Volume of metal removed per revolution= πDdf mm3

Volume of metal removed per minute = πDdfN mm3

Volume of metal removed in 't' minute = πDdfNT mm3

Volume of metal removed between tool grind = πDdfNT mm3

$$L = \pi DdfNT \text{ mm3} = 1000\ VdfT \text{ mm3} = VdfT \text{ mm3}$$

3.2 Tool specifications

Un-coated:

Wedge angle:77.1°

Back rack angle: 4.43°

Side rack angle: 4.67°

Relief angle or Clearance angle:

End relief angle: 8.85°

Side relief angle: 5.23°

Cutting edge angle:

End cutting edge angle:7.42°

Side cutting edge angle: 4.56°

Nose angle: 76.4°

Coated:

Wedge angle: 78.56°

Back rack angle: 4.38°

Side rack angle: 4.8°

Relief angle or Clearance angle:

End relief angle: 7.2°

Side relief angle: 8.1°

Cutting edge angle:

End cutting edge angle: 9°

Side cutting edge angle: 5.8°

Nose angle:68.8°

In the modification of tool, the thickness of the coating has been found using Scanning Electronic microscope. The figure 1 shows the tool used for experiment.Figure2 shows the microscopic image of the tool. Figure 3 indicates the coating thickness. The total thickness of the bilayered coating is found as 6 microns. Table 1-3 indicates the result output readings. Table 5 shows the cost analysis for modified tool implementation

4. Calculations

Length of the rod: 300mm

Ideal speed of the motor: 1460 rpm

Ideal speed of spindle or work piece: 1800 rpm

Constant speed of motor: 1300

Constant speed of spindle or work piece: 1700

Feed rate: 50.3 mm/min

Depth: 1mm

Initial diameter of the rod, D: 22mm

Final diameter of the rod, d: 16mm

$$\text{Cutting speed, } V = \frac{\pi \times 22 \times 1800}{1000} = 124.40\text{m/min}$$

Trial 1:

Coated tool:

$$\text{Weight loss percentage in coated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\%$$

$$= \frac{0.162}{67.16} \times 100$$

$$= 0.24\%$$

Un-coated tool:

$$\text{Weight loss percentage in uncoated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\%$$

$$= \frac{0.823}{67.703} \times 100$$

$$= 1.21\%$$

Trial 2:

Coated tool:

$$\text{Weight loss percentage in coated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\ \%$$

$$= \frac{0.31}{67.16} \times 100$$

$$= 0.46\%$$

Un-coated tool:

$$\text{Weight loss percentage in uncoated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\ \%$$

$$= \frac{1.403}{67.703} \times 100$$

$$= 2.07\%$$

Trial 3:

Coated tool:

$$\text{Weight loss percentage in coated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\ \%$$

$$= \frac{0.5}{67.16} \times 100$$

$$= 0.74\%$$

Non-coated tool:

$$\text{Weight loss percentage in uncoated tool} = \frac{\text{loss in weight}}{\text{Initial weight}} \times 100\ \%$$

$$= \frac{2.214}{67.703} \times 100$$

$$= 3.27\%$$

$$\text{Efficiency of coated tool} = \frac{\text{loss \% of non coated tool}}{\text{loss \% of coated tool}}$$

$$= \frac{3.27}{0.74}$$

$$= 4.41 \text{ times}$$

4.1 Cost Factor:

We have given special importance to reduce the expenses on manufacturing a product from beginning to the end. It's been noticed that, for manufacturing a product, analysis of cost estimation includes the satisfaction of customer with the quality. In this project, the cost estimation for modification of tool has been mentioned in table 4.

The surface finishing of the product is increased by the coated tool and hence it reduces the cost of quality control process. When a non-coated HSS tool is used, due to its tool life it requires reconditioning or replacement, which is not required for coated tool and hence it reduces the cost for replacements. The machining time required is very less for coated tool compared to the non coated tool.

Keeping the entire important factor for cost analysis the cost required for making a titanium nitride coated tool is very less. And increased tool life reduces the cost to buy a new tool or replacing an old tool.

5. conclusions

In this work, we have subjected both the tool to various types of test and works. The hardness and roughness value for both the tools have been taken under same conditions. The weight loss in the tool after each machining has been weighed using standard equipments. The different graphs have been plotted for both the tools as shown as loss in weight of the tool vs number of trials, loss percentage after each machining. From the above investigations, it is evident that the tool life of Titanium Nitride (TiN) coated tool is increased by 4 times than the Tool life of uncoated HSS tool.

Regarding the modeling it is found that response surface methodology combined with the factorial design of experiment are useful techniques for tool life testing. In this methodology, a relatively small number of designed experiments are required to generate much useful information that is used to develop the predicting equations for tool life. Depending on the tool life data provided by the design of experiment, first-order and second-order predicting equations can be developed. Furthermore, response surface methodology is a powerful tool for performing machinability optimization.

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