Investigation on HSS single point cutting tool manufactured using physical vapor deposition coating process

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Enhancement of wear resistance is of a major interest for the cutting tool industry. This work emphasizes the influence of bilayer coating on high speed steel single point cutting tool using physical vapor deposition technique. The high speed steel (HSS) substrate is coated first with TiN followed by coating of AlCrN. The microstructure of the coated tool is observed using scanning electron microscope. The hardness and wear resistance are determined for both coated and uncoated tools using Vicker’s microhardness test and tool weight loss percentage method, respectively. Corrosion test is carried out by salt spray test. The machining performance of the bilayer coated tools is evaluated and compared with that of the uncoated tools. The life of coated tools is about 4.41 times higher than that of uncoated tool.

Keywords: High speed steel, PVD, Coating, SEM, Hardness, Wear, Corrosion

Mild Steel is an extensively used material. The HSS tools are used for machining mild steel work-piece. HSS tool is easily available and inexpensive. Small scale industries and educational institutions are still using HSS tool for machining mild steel work-pieces. So that HSS tool is taken as substrate material. HSS tool has higher heat resistant and wear resistant properties than that of the high carbon steel. To increase the wear resistance of the tool and thereby improving the tool life surface coating is needed. To improve the surface roughness and increase the corrosion resistance the PVD coating is applied. By applying multi layer coatings on HSS to obtain coated HSS, whose performance competes with that of more advanced coated tools could be achieved at much lower cost. High speed steel (HSS) single point cutting tool (specification 3/8” × 4”) is used in engineering industries. Due to the continuous usage of this HSS, it will be subjected to high temperatures, high contact pressures and severe chemical reaction which will result in more wear. Several surface modification techniques, like physical vapour deposition (PVD) and chemical vapour deposition (CVD) coatings are used to coat cemented carbides, cermets. Cubic boron nitride (CBN) is frequently used to coat cutting tools for better tool life.

Among these two techniques, PVD is preferred as it is a line-off-sight process. In addition to this, thin coatings of thickness ranging from 3 µm to 10 µm can be deposited on sharp edge tools. Moreover, this technique can be performed without affecting the bare substrate material properties. Also the coating has good adhesion property. The range of deposition temperature is between 450°C and 950°C. The TiN coating is well known for its low coefficient of friction, higher hardness and high oxidation resistance. Tools coated with CrN using PVD process, high toughness, high hardness, low coefficient of friction and excellent wear resistance. Tribological behavior of TiN coating using PVD was investigated by means of dry and lubricated sliding wear test at room temperature and at 200°C. The wear test results revealed significant decrease in the wear of the tool steel under sliding wear test. Vera et al. have represented that depending on the experimental conditions the wear resistance property of CrN coating was better than that of TiN coating. The TiAlN coatings obtained by PVD technique was mostly used to enhance the performance and life time of conventionally used tool materials for their better characteristics, such as chemical stability, wear and high hardness. Metals coated with AlCrN were used for high temperature applications. TiAlN coatings have been studied in reciprocating sliding and ball on disc test for tribological behavior study.

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Tribological properties AlCrN coating was studied in various aspects\textsuperscript{21-28}. The interfacial bond strength of bilayer coated tool is higher than the uncoated tool\textsuperscript{30}. Though lot of work has been carried out using TiN and CrN coated carbides and cermet cutting tools very little work has been carried out on multiple layer coated HSS tools using PVD technique. Hence, this study is on the performance of TiN and AlCrN bilayer coated HSS tool using Physical vapor deposition technique and the effects of these coatings on mechanical properties and corrosion resistance.

Materials and Methods

High speed steel tool substrate was procured and wire cut electrical discharge machining was used to cut the samples into pieces for experimental work. The approximate size of the samples were 10 mm \times 10 mm \times 10 mm. The surface morphologies and the adhesiveness between the substrate and the coating were analyzed using optical microscope. The samples were thoroughly cleaned with ethanol/acetone mixture and washed with distilled water and dried before salt spray test. Samples of HSS tools coated with TiN, AlCrN bi-layer were prepared for micro hardness and surface roughness tests. Thermosetting plastic-Bakelite is heated above 160°C and moulded as a mounting placed in a cylindrical die. The samples for metallographic analysis were prepared by cutting, grinding and mirror polishing. The PVD coatings were applied using sputtering apparatus at a deposition temperature of approximately 475°C. CVD is a chemical reaction process. But PVD is the atomic state of ion deposition process. CVD coating layer may peel off during friction force. So PVD is so suitable compared with CVD.

Uncoated HSS tool of surface roughness, $Ra = 0.1 \mu m$ was loaded into the PVD chamber and the coating was applied for 6 h. The hardness was checked in coated and uncoated tool at same loading conditions. Moreover, a non contact surface roughness tester was used to determine the surface roughness of prepared samples. Scanning electron microscope (SEM) was used to analysis the wear and microstructure. Energy dispersive X-ray spectrum (EDX) was used to analyze the composition. Optical microscope (OM) was used to analyze the microstructure. The nomenclature and composition of cutting tool elements are shown in Fig. 1 and Table 1, respectively.

The bilayer of TiN and AlCrN were deposited on HSS tool substrate using physical vapour deposition method. In this work, stainless steel cylindrical vessel used as a vacuum chamber to carry out deposition process. Inside chamber pressure was detected by the wide range of gauges. In this experiment controlled vapour deposition with vacuum environment was achieved. Vacuum low enough to obtain good uniform deposition was maintained and a thickness of coating around 6 \mu m was achieved. Microstructural analysis was carried out on uncoated and bilayer coated test specimens using SEM. The surface roughness of uncoated and bilayer coated samples were determined. The microhardness of uncoated and coated samples was determined using Vickers hardness tester. Both the tools were used in centre lathe machine for machining mild steel work-pieces. The spindle speed of the machine is 50 m/min, depth of cut is 1 mm and feed rate is 0.25 mm/rev. The performance of both the tools were compared for same operating condition.

The uncoated and coated samples were subjected to an accelerated corrosion testing, i.e., salt spray test according to ASTM B-117-9 standard. The salt solution of 5 wt% of NaCl is continuously sprayed as a salt mist over the coated surface of the sample at 30° angle held on specimen table. The salt spray test was carried out for 24 h at room temperature. The exposed surface areas of all specimens were 1 cm\textsuperscript{2} and the remaining portion except the coated surface was waxed. Surface roughness of mild steel work-pieces machined by both coated and uncoated tools were determined using Taylor Hobson Talysurf non-contact surface roughness tester. The surface roughness measurements on bi-layer coated tool and uncoated tool were conducted using Taylor Hobson Talysurf surface roughness tester. Hardness test on

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<th>Table 1—Composition of HSS cutting tool</th>
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<td>Elements of HSS tool</td>
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<td>Composition wt%</td>
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Fig. 1—HSS Single point cutting tool nomenclature
coated tool and uncoated tools were conducted using Vickers microhardness tester at 1 kg load indentation. The tool wear tests were conducted on bi-layer coated and uncoated tools using weight loss method. The weight loss measurement equipment error is 1 mg.

**Results and Discussion**

The SEM image of bilayer coating of AlCrN coating over TiN coating is shown in Fig. 2.

Examination of SEM image of bi-layer coated HSS tool revealed a thickness range of 2.25-3.34 µm for AlCrN and a thickness range of 2.52-3.56 µm for TiN.

The composition of bi-layer coated and uncoated surface material is determined by X-ray energy dispersive spectrograph (EDX) at ambient condition and is shown in Fig. 3. From the results it is concluded that in the AlCrN coating the percentage of Al is maximum and sub elements, such as Cr and N are present in small quantity. It confirmed that in TiN coating, the Ti composition is found to be high. Figure 4a and 4b shows the wear test results. The test result clearly indicates less wear for bi-layer coated tool as compared to the uncoated HSS tool under same operating conditions. This may be attributed to superior hardness and wear resistance of both TiN and AlCrN coatings.

During the operating condition the uncoated tool surface nose is highly worn because of high co-efficient of friction and thermal expansion. However, the bi-layer coated tool nose surface is slightly worn in the operating condition. Since the TiN and AlCrN have higher yield strength and hardness. The morphology of tool edge was observed using SEM.
Figure 5(a) and 5(b) shows the surfaces of coated HSS tool and uncoated tool after salt spray test. It is observed that the coated HSS tool has more corrosion resistance as compared with that of uncoated tool due to the higher corrosion resistance of Al, Cr and Ti present in the coated HSS Tool.

Mild steel work-piece machined using uncoated HSS tool showed higher $R_a$ value (0.915 µm) and the mild steel work-piece surface machined using coated HSS tool showed lower $R_a$ value (0.155 to 0.259 µm). Qualitatively this indicates better surface finish of mild steel work-piece machined using coated HSS tool. Figures 6a and 6b show the 3D surface roughness images of the machined components. Better surface finish of mild steel work-piece machined using bi-layer coated HSS tool can be attributed due to the superior quality of the coated HSS tool cutting edge which deforms less as compared to the cutting edge of the uncoated HSS tool. The results show that the coated tool has a $R_a$ value 0.250 µm and uncoated tool has a $R_a$ value 8.50 µm. Therefore, the surface roughness of bilayer coated tool is better than that of uncoated tool due to the deposition of very small (nano) sized particles of the coating. The hardness of coated tool was found to be 1160 VHN and the hardness of uncoated tool was found to be 915 VHN. Therefore it is observed that the coated tool is harder than the uncoated tool due to the presence of hard nitrides.

Figures 7 (a) and (b) show the surface micrographs of bi-layer coated and uncoated HSS tools after machining the work-pieces in standard operating condition. It has been observed that the deep parallel grooves formed on the uncoated HSS tool. In the same time the bilayer coated tool has no evident of parallel
grooves on the surface. It is easily identified in the SEM micrographs. It is justified that the coated tool surface has no plastic deformation due to more hardness. But the uncoated tool has plastic deformation.

The wear test results are shown in Table 2. The results show that the life of bilayer coated tool is 4.41 times better compared to that of uncoated HSS tool due to the presence of wear resistant coating.

Conclusions

The experimental results show that the bilayer coated tool has a tool life 4.41 times that of uncoated tool. The bilayer coated tool has better surface finish. It was also found that bilayer coated tool has higher surface hardness and higher wear resistance compared to the uncoated tool. When mild steel specimen was machining using bilayer coated tool and uncoated tool, the surface finish of the mild steel work-piece machined with bilayer coated tool was better compared to that of work-piece machined with uncoated tool. Hence, it is concluded that TiN and AlCrN bilayer coated tool has better tool life, wear resistance, hardness and surface finish as compared to uncoated tool. Therefore, bilayer coating of HSS tool by PVD coating process is beneficial.

References