ADHESIVE WEAR BEHAVIOR OF TIN AND CRNCOATED DIN115CRV3 STEEL TOOLS AT DIFFERENT LOAD CONDITIONS

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Abstract- In manufacturing industry, the wear of cutting tools play a major role especially in surface roughness and finish quality of final products. In this study, hardened tool steel DIN 115CrV3 with superior mechanical properties was used as cutting tools. A physical vapor deposition (PVD) technique was performed for coating TiN and CrN on steels heat treated at 780°C. The adhesive wear experiments were performed at progressive and constant loads and then they were quantified and compared to hardened steel. Results of adhesive wear under progressive load showed lower friction of coefficient and friction force compared to ceramic coatings. The internal stress of hardened steel was found higher relative to TiN- and CrN-coated tools. The measurement of critical load of adhesion and delamination failure showed that CrN coating had better resistance than TiN coating. The hardened steel tools performed the worst adhesive wear at constant load compared to ceramic coatings. TiN-coated tools had better coefficient of friction values and adhesive wear properties at constant load than the others. Microstructure analysis of worn samples were used for characterization of wear properties of the samples.

Keywords- Adhesive Wear, Physical Vapor Deposition, Coating, Delamination.

I. INTRODUCTION

Selecting appropriate cutting tools and coatings play an important role in terms of cost and finish quality in machining operations. Wear of the cutting tools is unavoidableduring cutting operation. Adhesive wear is one of them and it result of loss of materials when contact surfaces under the influence of molecular forcesresult of breakage of bonds. This wear mechanism is usually leads to the formation of chip stacking edge between the edge and chip[1-6]. PVD coating application of wear resistant coatings on steel tools materials has proven to be successful in a variety of metal cutting applications [6-9].
Several studies have been conducted in this area in order to improve cutting performance. For example, Chung-Woo Cho and colleagues [10] carried out adhesive and abrasive wear tests on CrN coated 0.2% carbon steels. They found that the critical load of delamination increased when increasing thickness of the coating. Although, the early study realised by Lee and Jeong[11]confirm the findings of Chung-Woo Cho and colleagues [10], that the peel off the coating during adhesive wear is due to the increase of the critical load that is proportional to the thickness of the coating, but it is inversely proportional to the surface roughness of coating. Wilson and Alpas[12]verified the effect of coating thickness on adhesive wear. For this purpose, they TiN- coated AISI M2 steel with different thicknesses (2.5 and 3 μm). Pin-on-disc method is used for adhesive wear test under progressive load (20-250 N). They identified oxide particles on the surface when the applied load is reached to 20 N, at higher load, between 50-100 N the coating breaks beginning and after 100 N plastic deformation is observed.
The objective of this study was to quantify the adhesive wear behaviour ofunocated, TiN-coated and CrN-coated DIN 115CrV3 tool steels at progressive and constant loads.Wear mechanisms and properties of the samples were characterized by using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

II. MATERIALS AND METHODS

In this study, commercially available DIN 115CrV3 steel (diameter: 40 mm, length: 300 mm) was used as substrate material. The chemical composition of the steelwas given at the table 1. The samples are prepared to have 1 cm^2 of the surface area for the process.Samples were quenched at 780 ºC austenization temperature and temperedat 180 ºC.Hardened steel substrates hardness value was measured 820 HV.These substrates coated with TiN and CrN ceramics by Physical vapor deposition (PVD) method. The hardness of TiN coating was measured 1883 HV (thickness: 2.76 μm, surface roughness (Ra): 56.1 nm)after the coating process. CrN coating hardness was measured 1792 HV (thickness: 1.70 μm, surface roughness (Ra): 66.6 nm).

Table 1.Chemical composition of DIN 115CrV3.

Alloying Elements (Wt %)							
C	Mn	Si	P	Cr	V	Fe	Other Elements*
1,14	0,37	0,21	0,01	0,70	0,09	97,25	< 0,01

* Note: S, Al, Ti, As, Sn, Pb, Sb, B, Ni, Mo,Cu, Co

The adhesive wear testsat constant and progressive loadswere performed with CSM Tribometer (pin-on-disc) and CSM RevetestScratch Tester (RST) using standard ISO 20502 / DIN EN 1071.The experiments are performed at 23 °C room temperature with relative humidity levels of 30-35%. The wear experiments were repeated three times and theaverage results were used for comparisons.The test parameters of Pin-on-disc and Revetest Scratch Tester are given at table 2. The pin-on-disc test is carried out with Redhill brand ∅ 3 mm diameter tungsten carbide (WC)spheres. The wear tests were performed at constant 5 N load and 40 m wear distance.

Table 2.Wear test parameters.

Adhesive test		
Load Mode	Constant	Progressive
Initial Load	5 N	0.5 N
Final Load	-	30 N
Indenter Type	WC, Spherical	WC, Spherico-conical
IndenterDiameter	3 mm	Radius 100 µm
Length scratch	40 m	2 mm
Speed	5 cm/s	6 cm/s

The experiment with CSM RevetestScratch Tester is performed at progressive loads. The samples were placed between the fixed jaw holders before at the beginning test. Initial load of 0.5 N is applied, thenthe surface is scratchedat a rate of 59 N / minup to 30 N.A total distance of2 mm is scratched. The friction forces (Ft), coefficient of friction (Fs), acoustic emission (AE) were the recorded data for the tests.The images of scratched surfaces were taken after the tests. In addition, scanning electron microscopy (SEM-LEO 1430 VP) and energy dispersive spectroscopy (EDS) analysis were performed after the wear tests.

III. RESULTS AND DISCUSSION

Figure 1 shows the SEM images of CrN and TiN coated tools. TiN coating thickness had slightly thicker than the CrN. The average values of the thickness of coatings for TiN and CrN had 2.832 µm (figure 1a) and 1.928 µm (figure1b), respectively. In addition, both coatings show a good adherence to substrate without porosity and cracks. Globular metal carbides and martensitestructure was observed in the substrate region.

Figures 2 to 4 show the results of adhesive wear of hardened steel, CrN-coated and TiN-coated tools in progressive load, respectively. The friction force (Ft) of three materials increased with progressive load. Frictional force reached for hardened steel to 5 N (Figure 2), TiN-coated sample to 17 N (Figure 3) and CrN- coated to 15 N end of the tests (Figure 4). This preliminary results show that the friction forces of hardened steel tools is outperformed to ceramic coatings.

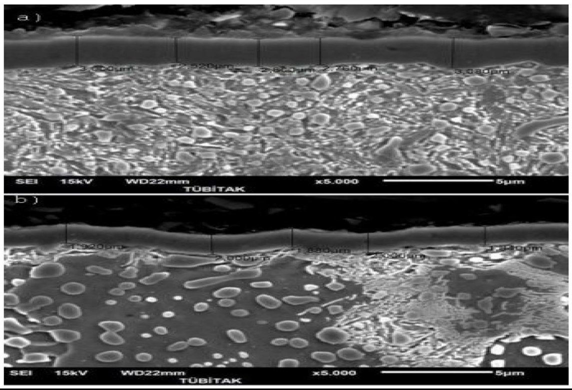

Figure 1.Cross-section view of a) TiNand b) CrNcoatings.

Coefficient offriction (COF) values of three samples were given in figure 5. The coefficient of friction values was increased with increasing wear distance for all three samples. The COF of TiN-coated and CrN-coatedwas observed to be close to each other throughout the experiment. During experiment, the plastic deformation gradually increased due to the increase of frictional force of TiN and CrN coatings and consequently, the increase of COF of the ceramic coatings was observed. On the other hand, higher COF is obtained for TiN after 2 mm. For hardened steel tools, the COF was found lower compared to ceramic coatings due to sliding effect on the martensitic surface. This difference is obvious after 1 mm up to the end of the experiment and sometime the variation/gap reachesthree times.

Acoustic emission is a result of the outside forces applied to the material resulting sound waves associated to the presence of internal stresses in the material. At the beginning acoustic emission values for hardened steel tools are the internal stress values.The addition of external stress to the internal stresses due to progressive loadresultedan increase of acoustic emission. Until tothehalf of the experiment the internal stresses reached the maximum value (100%). After that, the temperature of the surfaces is raiseddue to the increase of the frictional force and consequently, the effect of re-tempering showed a slight decline of stresses (Figure 2). For the ceramic coatings, the acoustic emission of TiN-coated tools was not exceeded 1% (see Figure 3) while for CrN-coated samples, the acoustic emission was ascending and descending until the end of the experiment that reached 10% of internal stresses (Figure 4). These values for coated samples compared to uncoated samples are extremely small and negligible internal stresses that minimize the risk of cracking.According to density of internal stresses under progressive load, the lower internal stresses was found forTiN following by CrN and the highest for hardened steel tools.

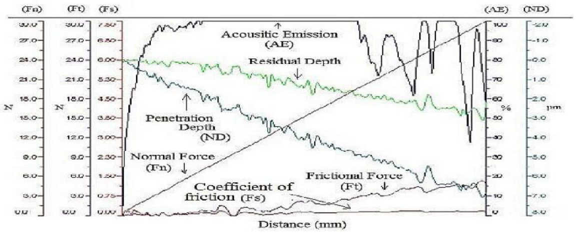

Figure 2.The friction force, acoustic emission and friction of coefficient behavior of hardened steel tools in progressive load.

A general overview pictures of deterioration of the surface of hardened steel, TiN-coated and CrN-coated tools after progressive load are illustrate at Figure 6 to 8. TiN and CrN coatings delaminated and disappear from the surface with the time associated to load increase (Figure 6a and 6b). This was not observed for hardened steel because of not presence of coating layer (Figure 6c). TiN and CrN coatings failed adhesion and delamination failure wear mechanisms (figure 6a and 6b).TiN coatings failure was began at the early stages of the progressive load experiments. When both coating is compared to each other in terms of adhesion failure and delamination critical load; CrN coating (adhesion failure load 10.36 N- delamination load 15.2 N) had higher resistance compared to TiN (adhesion failure load 5.32 N- delamination load 11.83 N).

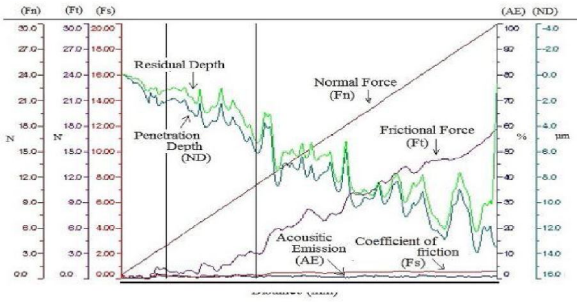

Figure 3.The friction force, acoustic emission and friction of coefficient behavior of TiN tools in progressive load.

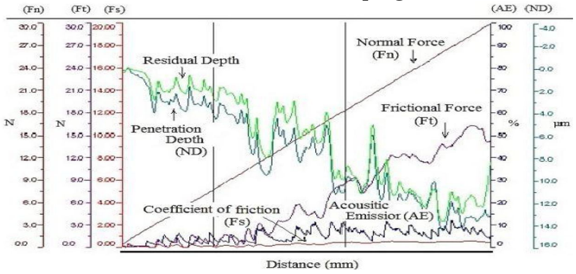

Figure 4.The friction force, acoustic emission and friction of coefficient behavior of CrN tools in progressive load.

Also CrN coatings are ductile, less brittleness and well adhesive properties to the main material than rival. These properties elucidate the higher critical load of CrN coating. Due to poor ductility of hardened steel, it was not showed a critical load..

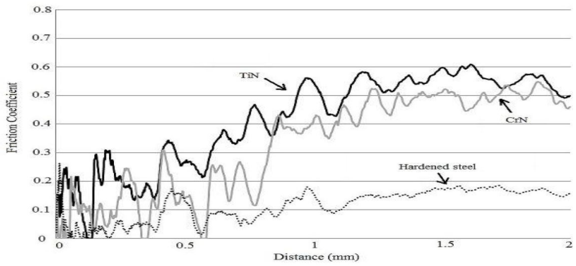

Figure 5.The coefficient of friction values ofsamples in progressive load condition.

The findings are compared with the existing literature, for example, Wilson and Alpas 's [6] results showed poor delamination critical load (5 N) for TiN. This difference is due to principally the main material used in the study, the researchers used high speed steel AISI M2 that had less surface roughness than cold work tool steel. Cho and Lee [10] results was similar to findings above in terms of delamination critical load values of CrN coating

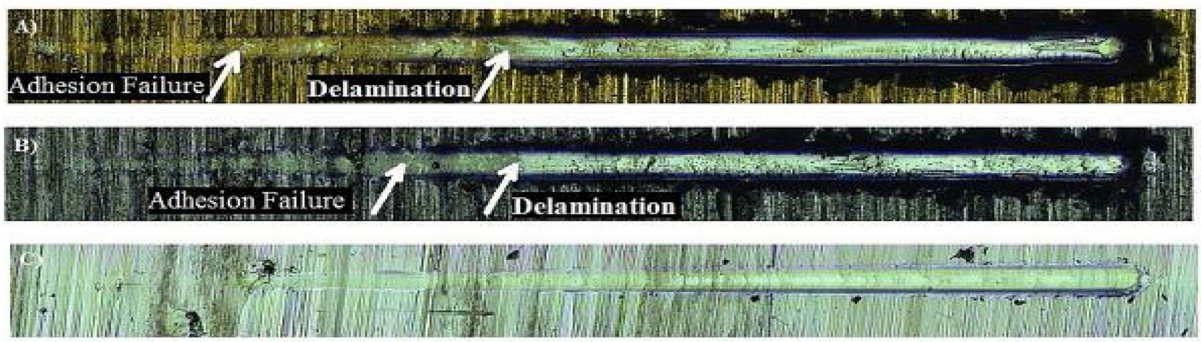

Figure 6. The surface damage of a) TiN b) CrN and c) hardened steel after adhesive wear of progressive load.

The adhesive wear performances of hardened steel, TiN-coated and CrN-coated tools under constant load (5 N) are given in Figure7. As can be seen from the graph, the COF of the hardened steel increased, but the ceramic coatings values remained nearly constant throughout the wear distance. Here, it should be noted that COF values highly increased for CrN-coated tools at the beginning of the experiment. In general, friction and wear increase when two materials contact each other at high pressure and temperature that it results oxidation and broken particles. During the experiment, the particles or oxidizedparticles broken from hardened steel were adhered to the main mass. Consequently, it increased the COF of hardened steel. TheCOF of hardened steel, TiN-coated and CrN-coated tools are reached after experiment respectively ~ 0.6, ~ 0.1 and~ 0.3. TiN-coated tools comparedto others toolshad the lowestCOF.

For hardened steel cutting tools the COF was found lower under progressive load compared to ceramics coatings cutting tools. However, under constant load opposite results is found in terms of COF. The COF valuesof CrN-coated samples obtained in this study are good agreement with the previous studies [2, 12-14]. On the other hand, the results obtained for the TiN coatings by Aihau[15]are found higher

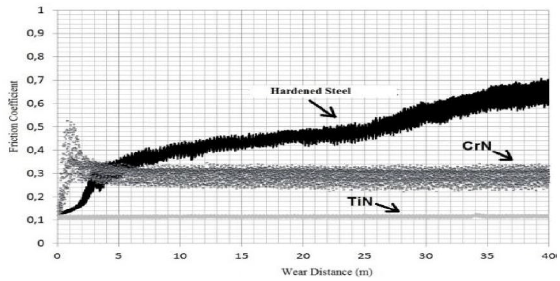

Figure 7.The coefficient of friction of tools under constant load

CONCLUSIONS

The ceramic coated and hardened tools made of DIN 115CrV3 steel showed different adhesive wear performance at different loads. The following results from this study can be emphasized:

- The adhesive wear under progressive load of hardened tools showed lower coefficient of friction than the ceramic coatings. However, the hardened steel had higher internal stresses than ceramic coated ones. The hardened tools had not performed a critical load of adhesion failure and delamination but, it was higher for CrN-coated tools compared to TiN-Coated.
- The coefficient of friction of ceramic coatings was lower compared to hardened steel tools at constant load; a TiN-coated tool wasoutperfomed to the rivals. The microstructure analysis of the worn surfaces showed presence of W elements in the hardened steel and CrNsamples which this results also confirmed the abrasion of the test sphere. The wear zone is more pronounced for hardened steel while it was intermittent for CrN.

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