Experimental investigation of CrN coating deposited by PVD Process

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Abstract. The aim of this study to analyse the tribological behaviour of chromium nitride coating on gray cast iron as substrate at room temperature in dry conditions. Gray cast iron alloy is extensively used in the automotive industry, was coated by the physical vapour deposition method. Pin-On-Disc tribometer was used for wear test at a simultaneous increase of loads (10, 20, 30 and 40N) and corresponding speed (0.5, 1, 1.5 and 2m/s) on mass loss, wear rate, the coefficient of friction was analysed. The wear mechanism is studied by the SEM micrograph, results in a transformation of mild to severe wear, followed three-body abrasion, and oxidation wear for dry conditions.

Key words: CrN, PVD, Pin-on Disc, Wear, Friction.

1. Introduction

The application of the hard coating by Physical Vapour Deposition (PVD) in single or multilayer become popular due to its wear and corrosion resistance in some broad applications. The quality of the PVD coating related to various aspects like thickness that depends upon application ranges from few hundred nanometers to 50 micrometres, adhesion of coating, surface roughness and hardness etc. [1]. Chromium nitride (CrN) came to be more popular as a thin film coating for the automotive industry and various tools, and it showed lower wear rate compare to ZrN and TiN about one and two orders, respectively [2].

Hacisalihoglu et al. [3] studied several coating have nitride phase (TiN, TiCN, AlTiN and CrN) deposited by PVD on AISI M2 high-speed tool steel subjected to 5 N normal load and 8 mm/s against Al2O3 with linear reciprocating tribometer. The lowest worn volume was obtained from CrN coated surface under such experimental parameters. Bandeira et al. [4] deposited CrN coating by PVD on plasma-nitrided AISI 4140 steel and investigated wear behaviour in ball-on-disc configuration against Ø 6.35 mm Si3N4 ball at 10 N normal load and 0.01 m/s sliding speed. The wear rate and coefficient of friction of both uncoated and coated samples reduced significantly in lubricated conditions due to physical and chemical reactions of lubricants with the sliding surfaces. Shan et al. [5] investigated
multi-arc ion plated CrN coatings on 316L stainless steel against WC ball in artificial seawater and subjected to 5 N normal load and 25 mm/s speed.

Nevertheless, knowledge of wear behaviour of the CrN coating is still missing. Therefore, the aim of this experimental investigation is to evaluate dependency of the friction coefficient and wear rate of CrN coating on the successively increase of load and velocity.

2. Materials and methods

Gray cast iron alloy is used as a substrate material and atomic deposition process is used for coating the material, due to its adhesive property during the deposition of ceramics and metal alloy in an extensive range of shape. For better deposition and columnar structure of CrN the substrate needs to preheated. Better fabrication technique, and automated control of its process parameters makes it popular due to inherent quality of coating. PVD device was used to deposit the coating system. Sample was heated approximately up to 450°C temperature during the coating process. The vacuum chamber contains of a carrier gas (nitrogen) and acetylene with the argon in rest condition at a pressure of 520-550 MPa. CrN deposition was carried out with an atomic deposition arrangement, working in a nitrogen atmosphere. A power source of 2500–2750 Watt was set for cathode power associated with adjusted pulse frequency so that the chamber temperature increases and results to change in nitride phase of nitrogen at a temperature around of 1536 °C with chromium.

3. Experimental Setup

A Pin on Disc tribometer is used to study the wear behaviour of the coating, works on WinDucom software. The machine has the control system with the data acquisition system analysis and recording. CrN coated sample is mounted on the disc as shown in Figure 1. Load was applied on the pin with the help of pulley string arrangement and the tribometer had the highest loading capacity of 200 N. wear test has been performed at room temperature (25°C) by varying loads (10, 20, 30 and 40N) and speeds (0.5, 1, 1.5, and 2m/s) successively for a constant duration of 1000 seconds. Counter-body(pin) and the coated sample (Disc of CrN) has been cleaned before and after each wear test to remove the accumulating of wear debris. Further weight is measured by the weighing machine of the electronic weight balance of least count 0.00001 g is used.

Figure :1 Experimental set-up of Pin-On-Disc tribometer [6]
4. Results and Discussion

4.1 Weight loss

Weight loss is also one of the easiest way to predict the wear behaviour of the coating by pin on disc tribometer. Figure 2 depicts the trend of mass loss of the coated sample (Disc) and counter-body (pin). It can be seen that the weight loss of pin and disc in decreasing with the successive increase of load and speed. The mass loss ranges from 0.0062-0.0031 for pin and 0.0082-0.0039 for the CrN coated sample. At lower sliding speed (0.5m/s) and load (10N) the weight loss of pin and disc 0.0062 gram and 0.0082gram has been recorded. With the increase of load 10 to 40N and speed from 0.5m/s to 2m/s the weight loss of pin and disc is 0.0031 gram 0.0039 gram.

Weight loss of the coating is dependent upon the structure, chemical composition, metal transfer and formation of transfer layer at the counter-body. This decreasing trend is due to the formation of an oxide layer at the interface. Due to the successive increase of load and speed the rise of temperature also take place at point of contact. The rise in temperature may cause partial melting of the wear debris that is entrapped at the point of contact.

![Weight loss of CrN coated sample (Disc) and Pin](image)

4.2 Specific wear rate

Specific wear rate is comparatively more reliable empirical method to represent the trend of CrN coated sample. It can be solved by the equation suggested by Holmberg and Matthews as a standard for wear test [7]. Figure 3 depicts the behaviour of wear coefficient of the CrN coated sample. The wear rate ranges from 10.32×10^{-5} mm³/Nm to 0.9186 ×10^{-5} mm³/Nm. The wear coefficient of chromium nitride decreasing due to the formation of nitride phase and fine columnar microstructure that reduced the particle pull-out from the coating during wear test. When the hardened phase of the coating worn away from the surface then it leads to another stage of that is the failure of coating. Similar results also reported in the decreasing trend of wear coefficient at a constant sliding distance with increase in speed due to the work hardening of wear surface, clogging, attrition, and shelling of abrasive particles [8-9].
4.3 Coefficient of friction

Figure 4 shows the evolution of friction coefficient at the interface of chromium nitride coating. The average value of the steady-state region has been taken to plot the graph. The coefficient of friction (COF) has been recorded 0.25 at 10N load and 0.5m/s speed. Whereas the load and speed is increasing till 20N and 1m/s the COF is 0.20. At 30N load and sliding speed 1.5m/s the value of COF is 0.17. At the maximum operating parameters that is 40N load and speed 2m/s the COF is 0.14. The above results are indicating lower COF with increase in load and speed, this is also supported by the low wear volume of coating. Initially the COF is high because at the interface of pin and disc the adhesion between the surface settle down. Further it is decreasing because increase in speed overrides the increase in load results to decrease in friction coefficient. Similar
4.4 Wear mechanism

In order to study the wear mechanisms of chromium nitride coating dependent upon the real contact conditions at the interface. Study of wear track by the scanning electron microscopy in Figure 5 gives the wear mechanism such as elastic and plastic contact with abrasion and adhesion with the combination of oxidation as a dominant wear mechanism. The micrograph is showing some plastic deformation caused by dislocating due to the interface accumulated under enough adhesive bonding. Such type of wear mechanism at the point of contact called adhesive wear. In Figure 5(b) two surfaces interlocking results of deep grooves and ploughing so that a certain volume of metal removal can be clearly seen generated by the mechanism of micro-cutting. Whereas some metal transfer in the direction of motion can be clearly seen in the SEM micrographs. Some of the common wear mechanism like abrasive due to the pushing action of pin at CrN coated disc that is subsequently retracted, and loss of material takes place [10].

![Figure 5 Wear track micrograph by SEM](image)

5. Conclusions

A practical application about the friction and wear behaviour of CrN coating has been summarized in this paper. Specific wear is decreasing with simultaneous increase of load and speed, ranges from $10.32 \times 10^{-5} \text{ mm}^3/\text{Nm}$ to $0.9186 \times 10^{-5} \text{ mm}^3/\text{Nm}$ due to the formation of nitride phase and fine columnar microstructure that reduced the particle pull-out from the coating during wear test. Whereas the friction coefficient decreasing from 0.20 to 0.14 due to increase in force from 10 to 40N. Wear mechanism such as elastic and plastic contact with abrasion and adhesion with the combination of oxidation as a dominant wear mechanism.
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