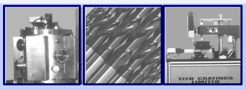

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The Friction and Wear Properties of CrN, Graphit-iC and Dymon-iC Coatings in Air and Under Oil - Lubrication.

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1. Introduction

Hard ceramic coatings such as TiN and CrN are very successful and are widely used in improving the performance of cutting and forming tools, but they are less successful in providing protection for general machine components, such as gears and engine parts. The development of low-friction wear resistant coatings that can run dry or in a minimum amount of oil is becoming increasingly important to this industry. Two recently developed carbon-based coatings: Graphit-iC™ and Dymon-iC, which are shown to exhibit very high sliding wear resistance and low friction in dry conditions, are compared to a CrN coating under oil lubricated conditions. Long term pin-on-disc tests using a chrome steel counterface ball were carried out on coated HSS test samples.

2. Deposition of CrN, Graphit-iC and Dymon-iC films

All the coatings were deposited in a Teer industrial closed field unbalanced magnetron sputter ion plating (CFUBMSIP) system, as shown in Figure 1. In all the cases the substrates were Ar plasma ion cleaned using pulsed DC bias prior to coating deposition and a thin, approximately 0.2 µm, adhesion promoting Cr layer was first deposited by DC magnetron sputtering, again with a pulsed DC bias. To produce the CrN coating, nitrogen was introduced into the chamber after deposition of the initial Cr interlayer. For the Graphit-iC coating, a ramp layer was produced by decreasing power on the Cr targets used for the interlayer and increasing power on the carbon targets from zero to full power. This was followed by deposition of a C/Cr multilayer that was deposited by rotating the sample in front of each target. For the Dymon-iC coating, the Cr layer was followed by a CrC layer, by the addition of butane, controlled via a closed-loop Optical Emission Monitoring (OEM) system. Finally an a-C:H layer was deposited using a pulsed DC bias on the substrate and a discharge enhancing electrode with a 13.56 MHz RF generator. The substrate temperature was measured as less than 300 °C for each coating deposition.

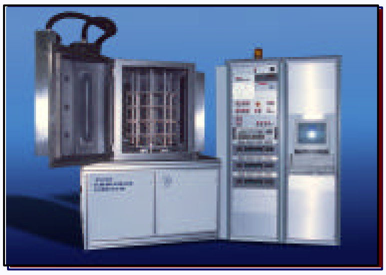

Fig. 1: Teer industrial CFUBMSIP system

3. Characterisation of the films

Adhesion was measured using a Teer Coatings ST3001 scratch tester with a 0.2 mm tip radius Rockwell diamond indenter. The diamond tip was drawn across the coating with a loading rate of 100 N min^{-1} and a sliding speed of 10 mm min^{-1}. A standard hardness tester (Wilson / Rockwell B503-R) using a 150 kgf load was used to assess the adhesion of the coatings. Plastic microhardness was measured using a Fischerscope H100 ultramicro-hardness tester with a load of 50 mN. For indentation depths of more than 10% of the coating thickness a composite hardness value was obtained. Coating thicknesses were assessed using a ball crater taper-section technique.

Fig. 2: Teer Pin-on-Disc wear tester

Pin-on-disc (Figure 2) sliding wear tests were performed on the coated samples using a Ø5 mm chrome steel (AISI 52100) ball with a surface finish better than R_a = 0.05 ? m as the counterface. The counterface ball was fixed and the coated samples were positioned beneath. Each sample type was tested at a normal applied force of 40 N giving a maximum contact pressure, at the end of the test, in the region of ~1.6 GPa. A sliding speed of 0.2 m s^{-1} was used for all the tests. The tests in air were carried out for a sliding distance of 720 m (1 hour) and for the tests in oil a sliding distance of 7200 m (10 hours) was used. The frictional force generated by the sliding was recorded. The wear depths of the coatings were calculated from taper cross-sections produced by ball cratering through the wear track. Tests were performed in normal laboratory atmosphere (20 ? 5?C, 45? 10% RH) and semi-synthetic oil (10W 40).

4. Results and Discussion

The thickness, hardness and adhesion results are presented in Figure 3. All the coatings showed good adhesion to the substrate.

Coating	Total Thickness / µm	Composite Hardness / GPa	Critical scratch load (Lc) / N	Rockwell C Indent (HF1 to 6)
CrN	3.6	21.9	80	HF1
Graphit-iC	2.5	17.9	90	HF1
Dymon-iC	1.6	14.5	90	HF1

Fig. 3. Mechanical properties of the coatings.

Coating	Test environment	Friction coefficient	Coating SWR (x 10^{-17}m^{3}N^{-1}m^{-1})	Ball SWR (x 10^{-17}m^{3}N^{-1}m^{-1})
CrN	Air	0.80	20	305
Graphit-iC	Air	0.12	3.2	1.1
Dymon-iC	Air	0.07	1.9	0.3
CrN	Oil	0.10	0.04	5.3
Graphit-iC	Oil	0.08	0.003	0.43
Dymon-iC	Oil	0.10	0.01	0.06

Fig. 4: Pin-on-disc friction and wear properties of the coatings.

All the friction and wear results are presented in Figure 4. The wear track and ball surface of the coatings after pin-on-disc testing in air and oil under a load of 40 N are presented in Figures 5 and 6. All three coatings survived the sliding distance (i.e. no penetration into the metallic adhesion layer or the substrate) in air and oil with the Dymon-iC coating having the lowest friction coefficient of 0.07 when tested in air. The CrN coating produced the highest friction coefficient and also exhibited the highest specific wear rates of the coating surface and counterface ball. The Graphit-iC and Dymon-iC coatings showed lower coating specific wear rates of 3.2 and 1.9 × 10^{-17} m^3 N^{-1} m^{-1} respectively, and much lower ball specific wear rates of 1.1 and 0.3 × 10^{-17} m^3 N^{-1} m^{-1} respectively, compared to the CrN coating when tested in air. In general, for the carbon-based coatings tested in air a transfer layer developed onto the surface of the ball which helped to protect the coatings from severe wear. Under oil all the samples showed negligible coating wear and all had a friction coefficient of ~ 0.1. However, the wear of the ball was much higher for the CrN coating. The worn ball surface micrographs shown in Figures 5 and 6 emphasise how much the ball is protected from wear in air or under oil lubrication when run against the carbon-based coatings.

Fig. 5: Taper cross section of coating wear track and wear scar on chrome steel ball following testing of coatings in air under an applied load of 40 N after a sliding distance of 720 m

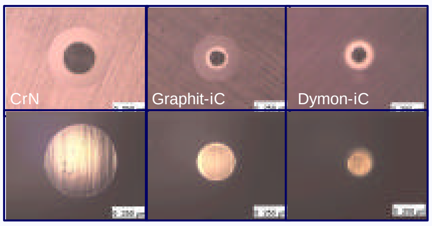

Fig. 6: Taper cross section of coating wear track and wear scar on chrome steel ball following testing of coatings in oil under an applied load of 40 N after a sliding distance of 7200 m

5. Conclusions

Pin-on-disc tests run in air showed that the carbon-based coatings produced the lowest friction coefficient, coating wear and also protected the counterface ball against excessive wear. For these coatings a transfer layer was observed on the ball after the tests which contributed to the lower friction behaviour and the protection of the counterface ball. Compared to the CrN coating, the carbon-based coatings reduced the overall wear dramatically. In an oil environment, the coefficient of sliding friction was ~ 0.1 in all cases. While all the coated surfaces exhibited low wear when tested under oil lubrication, both carbon-based solid lubricant coatings also dramatically reduced the amount of counterface wear when compared to CrN - an example of the more commonly used hard nitride coatings.

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