RUNNING-IN OF DLC COATED STEEL IN BOUNDARY LUBRICATION

N. STAVLID and U. WIKLUND

Department of Materials Science, Uppsala University
Box 534, SE-751 21 Uppsala, SWEDEN

The benefits of using DLC coatings on steel in dry sliding are well known. The present study has investigated the effects of using the same materials but in a boundary lubricated environment. Tribological tests were performed using a load-scanning device and a lubricant with an extreme-pressure (EP) additive. XPS and grazing incidence XRD are used for chemical analysis. The chemical composition of the resulting tribofilm is correlated to different friction behaviors and contact loads, and indicates that high loads are beneficial for formation of low friction tribofilm.

Keywords: DLC, tribofilm, XPS, EP-additive

1. INTRODUCTION

Dry sliding between steel surfaces results in a friction coefficient of about 0.6 and often a pronounced wear. The friction and wear may be lowered if one or both of the surfaces is coated, using a wear resistant low friction film such as diamond-like carbon (DLC) [1]. Such films are thought to have a prospective future when used on mechanical components in order to increase lifetime and lower energy consumption through reduced friction. There are a large number of DLC coatings available for these purposes produced using physical vapour deposition (PVD) and chemical vapour deposition (CVD) techniques and ranging from pure carbon to carbon doped with various metals. More details about the process for producing DLC films can be read elsewhere [2-3].

No matter if the contact is dry or boundary lubricated, wear debris and chemical reactions always create tribofilms on the surfaces. These tribofilms actually control the friction and protect the original surface from further wear. The time required to form a protective tribofilm can be said to correspond to the running-in of the tribo-system.

This work aim to study such tribofilms formed under boundary lubrication and how the degree of running-in influences their formation.

2. EXPERIMENTAL

2.1 Test set-up

This investigation was based on sliding tests using a load-scanning device, see Figure 1, further described in [4].

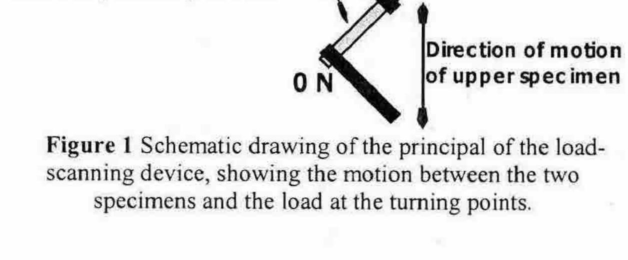

Figure 1 Schematic drawing of the principal of the load-scanning device, showing the motion between the two specimens and the load at the turning points.

The contact area is boundary lubricated, simulating a mechanical component in a contact with limited lubrication, which is typical for many components before running-in.

For the reciprocal motion the load-scanning device was set at a sliding speed of 65 mm/s. Each stroke was 90 mm long during which the load is increased from 0 at one endpoint to 1200 N at the other. Tests durations were selected from one cycle up to a maximum of 7000 cycles. The friction force and normal load were monitored several times throughout each stroke.

Lubricant was filled in a surrounding compartment so that the specimen in the lower holder was flushed with a wave of lubricant when the movement changed direction. This was to ensure that the same lubrication was preserved throughout the test.

2.2 Materials

The material used was ball bearing steel (BBS) named SS 2258. The steel rods that are DLC coated had a hardness of ~770 HV. The uncoated specimens were heat treated to a hardness of ~750 HV, i.e. that is somewhat softer than the substrate. This is to avoid cracking of the thin film [5]. All rods were centre-less ground resulting in a surface roughness of $R_a = 0.1$ µm.

The coating was a commercial tungsten doped DLC coating with a hardness of about 1000 HV.

The base oil was a poly-α-olefin (PAO) with a kinematic viscosity of 8 cSt at [illegible] 2.25 vol% EP-additive, olefin sulphide, was used.

In order to see the combined effect of using DLC coating and additive in the oil, different combinations were tested. See Table 1.

Table 1 Test matrix

Lubrication \ Materials	DLC / BBS	BBS / BBS
PAO + EP-additive	X	X
PAO	X	X

The emphasis was put on DLC sliding against uncoated steel using a lubricant containing EP-additive, since that was the most promising combination.

3. RESULTS

Typical behaviour of a system with EP-additive when DLC is sliding against BBS is shown in Figure 2. The higher load have both a lower initial friction and a more pronounced running-in.

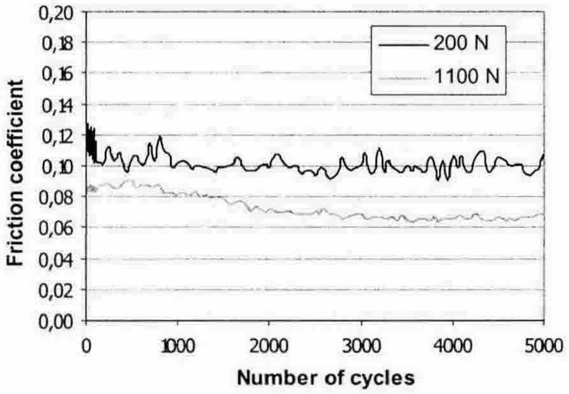

Figure 2 Comparison between a high and a low load position when DLC is tested against BBS for 5000 cycles using the lubricant with EP-additive.

The chemical compositions of the tribofilms produced at the same two loads after 5000 cycles are shown in Figure 3. There is clearly much higher tungsten content at the high load position than at the low load position. Only tungsten and sulphur are shown, but oxygen, carbon and iron were also analysed and included when calculating the atomic percentages.

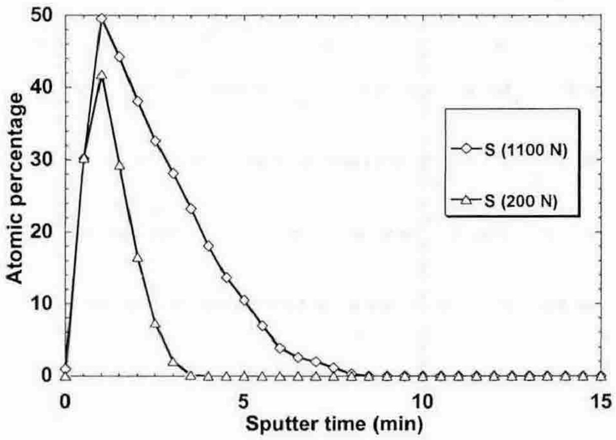

Figure 3 XPS depth analysis of tribofilms, W and S concentration for a high and a low load after 5000 cycles.

Grazing incidence (G.I.) XRD analysis of the tungsten rich tribofilm, formed at 1100 N load, show a degree of crystalinity as seen in Figure 4. Since the tribofilm thickness is small the peaks are broadened. Complex Fe-W sulphides are formed, iron-tungsten carbonyl sulphide being one possible composition.

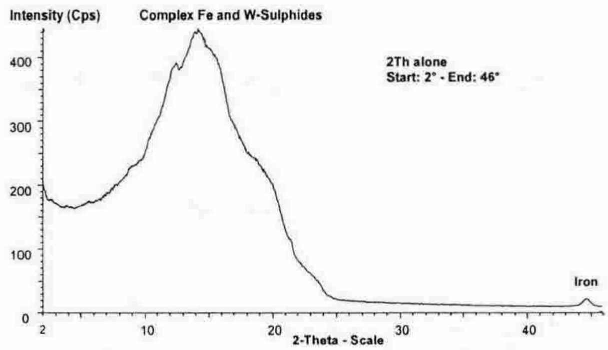

Figure 4 G.I. XRD analysis of high W content tribofilm.

4. DISCUSSION

According to friction curves and the chemical compositions there are mainly two main different tribofilm compositions present. One being the low friction film with high tungsten and sulphur content, resulting from higher loads and / or many cycles. The lower loads are not sufficient to provide enough tungsten transfer to the tribofilm. Individual spectra of tungsten peaks, using XPS, show a broadening and a chemical shift indicating a chemical bonding as sulphides.

Since the main constituent in the film is iron, it is believed that a mixed iron-tungsten sulphide is present. This is also supported by the XRD analysis.

In the case of DLC sliding against steel a tribofilm was only formed on the steel surface.

The tribofilm thickness was estimated to be less than 150 nm, according to light interferometer profiles obtained from sputtered holes using the XPS.

The same experiments ought to be performed in an inert or oxygen free environment to explore the importance of oxygen on the tribofilm composition.

5. CONCLUSIONS

As shown in this study a higher load is beneficial for the formation of a low friction tribofilm when sliding DLC against steel in boundary lubrication combined with an EP-additive. Therefore it is possible to expect that a "harder" initial running-in of a component could be beneficial. Thereby producing a low friction film, which is capable to protect at the lower "in-service" loads.

6. REFERENCES

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