FRICTION AND WEAR OF DIAMOND-LIKE CARBON COATINGS LUBRICATED WITH BIODEGRADABLE OILS

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ABSTRACT

The tribological behaviour of coated machine components lubricated with a biodegradable saturated ester and unsaturated ester oil has been studied. Different diamond-like carbon-based coatings (DLC) were selected as low friction coatings: pure DLC, Si-doped, Ti-doped and W-doped DLC. The performance of the studied ester oils has been compared with sunflower oil and mineral oil lubrication as reference. The oils were all additivated in the same way with conventional anti-wear (AW) and extreme pressure (EP) additives. Different tests have been performed: disc on disc, ball on disc and block on ring tests give an overview of the influence of different sliding modes. The effect of the lubricant on a coated system compared to the use of the coated system without lubrication is clear for the wear, but less obvious for the friction. It was found that DLC/DLC contacts lubricated with biodegradable lubricants show similar friction as steel/steel contacts. The effect of the different types of base oil is independent of the coating type. Additive activity which was clear in steel/steel contacts was not obvious in DLC/DLC contacts.

INTRODUCTION

During the last couple of decades environmental awareness has risen considerably. One of the major concerns in the area of lubrication is the amount of lubricants lost into the environment, not necessarily by major oil spill incidents but rather in the course of routine usage – e.g. in open lubrication systems such as chain saw oils or leakage of fluid from hydraulic and gear systems [1]. Emission of lubricants to the environment is unavoidable. This is especially a problem for activities in sensitive environments such as marine and forestry.

A solution to avoid extensive soil and water pollution is the use of environmentally friendly lubricants. However, one of the major disadvantages of biodegradable oil based lubricants is the lower resistance to thermal oxidation leading to lubricant degradation. Frictional heating, especially severe during accidental contacts of the moving parts or during start-up and shut-down contacts, limits thus the lifetime of such environmentally adapted lubricants (EAL).

The use of advanced low friction coatings (LFCs) such as diamond-like carbon (DLC) coatings could offer an innovative solution to these problems. Different DLC types are tested in combination with unadditivated and additivated biodegradable oils and their tribological behaviour characterised.

EXPERIMENTAL SET-UP

The tested coatings are summarized in table 1. The lubricants used were a mineral oil (M), a saturated (SE) and an unsaturated ester (UE) with anti wear additive(AW/EP) and extreme pressure additives (EP) or fully formulated (opt) [2-3].

Tests have been done in three test set-ups. First, tests with low contact pressure (4 MPa) have been performed in ring on ring tests, with the flat sides of the rings running against each other at 0.5 m/s. both test rings are coated. The aim was to study the effect of lubricants and additives on friction and wear of coatings without disturbing effect of the steel counterpart. The materials were heated to 80°C since additives only work at high temperature.

Secondly, ball on disc tests have been performed with the disc coated and a steel ball counterface, and reversely, with a coated ball and steel disc counterface. Typical test conditions were 0.1 – 0.26 m/s; 1.3 GPa Hertzian stress and 80°C.

Finally, block on ring tests have been performed with a coated block on a steel ring. In this case the lubrication was starving, i.e. The test ran 8h, but only the 10 first minutes lubrication was provided (speed was 0.1 m/s, load 90N).
Table 1: Tested DLC coatings

<table>
<thead>
<tr>
<th>Code</th>
<th>Deposition method</th>
<th>Layer structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLC-1</td>
<td>RF PACVD (13.56MHz)</td>
<td>a-C:H single layer</td>
</tr>
<tr>
<td>DLC-2</td>
<td>Hybrid process PVD/CVD</td>
<td>a-C:H single layer</td>
</tr>
<tr>
<td>Si-DLC</td>
<td>Low frequency PACVD</td>
<td>a-C:H/a-Si:O single layer</td>
</tr>
<tr>
<td>Ti-DLC</td>
<td>Reactive magnetron</td>
<td>Ti-C:H single layer</td>
</tr>
<tr>
<td></td>
<td>sputtering + PACVD</td>
<td>a-C:H/a-C:H-W multilayer</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

In dry conditions which may accidentally happen, the coatings have a beneficial, reducing effect on the friction (figure 1) and also the wear is lower. Coatings are however also beneficial when the system is lubricated. The coefficient of friction (COF) in the ring on ring tests running with ester oils is lower than in the uncoated system. The lowest COFs are obtained for the DLC-1 coating. In general, DLC-1 and DLC-2 show the least wear.

The effect of the different types of base oil is similar regarding to the coating type. There is a slightly higher COF for most coatings when the mineral oil is used compared to other oils. The lowest coefficients of friction are obtained with the SE and UE oil, and lowest wear is also obtained with UE. The other types of lubricant also show the same or less wear than the mineral oil M. The effect of the additives is not clear in the ring on ring tests and the COFs and wear of the additivated oils is in general near the COF of the base oil.

Ball on disc wear tests showed that applying a coating at one face reduced the wear in dry conditions (without lubricant). Even in the case where a lubricant was used, applying a coating reduced the wear of the samples further. Whereas the effect of additives on the resulting component wear is clearly visible for steel-steel contacts, the effect of the additives seems not present or certainly in a much lower degree when a diamond like carbon coating is applied on one side of the contact. This conclusion suggests that additive reactions preventing for wear are less important in these coated contacts.

An effect of additivation on the delamination of the coating was found in long running experiments. If EP additive is used the doped coatings suffer not as much delamination and consequently show less wear. For the undoped coatings the opposite tendency is seen.

Based on the results of the block on ring tests (figure 2), it was observed the wear of the pin is reduced by 10 in dry conditions, only by applying the coating. In the case when the contact is slightly lubricated in the beginning of the test, the coefficient of friction is the same for uncoated and DLC-2 coated pins. The wear rate is lowered by a factor 10 (for DLC-2 combined with UEopt) to a factor 40 (for the DLC-2 combined with SEopt) compared to the uncoated pin.

In conclusion, when critical components (components that have to work in severe load conditions) would be coated with DLC, the inherent lower friction would allow the use of low additivated lubricants that are less toxic to the environment. On the other hand, classically formulated oils can be used in (partly) coated systems without problem, and at the same time benefit from the low friction properties of the coatings during start-ups and accidental dry running periods.

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