DEGRADATION OF W-DLC COATINGS IN ROLLING/SLIDING APPLICATIONS

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ABSTRACT

W-DLC coatings have demonstrated the benefit to improve contact fatigue life in different applications. The understanding of coating degradation mechanism becomes important for coated component design. In this present study, FZG gear rig has been used to investigate coating wear. The testing procedure was designed to monitor coating wear with interruptions. Scanning Electron Microscope and surface profilometer were used to characterize coating wear. Cone-shaped micro particle pullouts were observed at low stress cycles. Fracture-based cohesive delamination is one form of coating wear associate with concentrated stresses. Another form of wear is characterized as polishing wear (or, sliding wear). The mechanism of polishing wear is complex and can be attributed to chemical or oxidation wear and abrasive wear. However, unlike fracture-based cohesive delamination, polishing wear results a smoother surface. The evolution of surface topography due to coating wear is demonstrated by profilometry measurements. Wear mode of W-DLC coating degradation is proposed as a combination of cohesive delamination and polishing wear.

1. INTRODUCTION

W-DLC coatings have been used for rolling/sliding applications to improve reliability and durability of components experiencing extreme pressure associate with high sliding [1]. Such improvements include contact fatigue life and scuffing resistance. The lab testing demonstrated the feasibility of significantly improving component life by W-DLC coatings. The component life is governed by coating wear, instead of catastrophic failure mode as seen on uncoated components. However, the understanding of coating wear mechanisms and property-performance relationship is limited. W-DLC coated gear surface was characterized after endurance testing. Polishing wear was identified as coating wear mechanism [2].

The present study uses FZG gear rig to investigate coating wear. The testing was interrupted at different stress cycles for inspection. Scanning Electron Microscopy (SEM) and stylus profilometer were used to characterize coatings. Degradation mechanism for W-DLC coating was proposed.

2. GEAR TESTING

Table 1

<table>
<thead>
<tr>
<th>Applied Torque [N•m]</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>155</td>
<td>310</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Pinion Speed [rpm]</td>
<td>1850</td>
<td>1850</td>
<td>925</td>
<td>1850</td>
</tr>
<tr>
<td>Testing Time [min]</td>
<td>5</td>
<td>35</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>Accumulated Time [min]</td>
<td>5</td>
<td>40</td>
<td>47</td>
<td>87</td>
</tr>
<tr>
<td>Testing Pinion Cycles</td>
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<td>6475</td>
<td>6475</td>
<td>74000</td>
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<tr>
<td>Accumulated Pinion Cycles</td>
<td>9250</td>
<td>74000</td>
<td>80470</td>
<td>154475</td>
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</tbody>
</table>

FZG gear rig was used for W-DLC coating degradation study. Gears were manufactured by SAE4122 steel with carburized and hardened heat treatment, followed by grinding process. SAE grade 50 lubricant was used with supply temperature of 82°C. In order to investigate coating degradation, an interrupted testing procedure was used for inspection. The testing condition in each step is summarized in Table 1.

The test was stopped at the conclusion of each step and pinion and gear were inspected, which involved surface topography measurement and SEM analysis.

3. COATING DEGRADATION ANALYSIS

W-DLC coated pinion teeth were inspected before testing. The SEM image is shown in Figure 1. The micro-particles observed are cone-shaped in columnar structure, which grew from substrate during the deposition. The first interruption of the test was at 9250 stress cycles with low load and high speed (Step 1). As shown in Figure 2, Micro-particle pullouts were observed near LPSTC (lowest point of single tooth contact), where gear mesh experienced high stress and high sliding. The size of the pullouts is less than 10µm in diameter. Substrate exposure was observed at some
of the pores generated by the pullouts. The edge of these pullouts could be a stress riser, which leads to delamination along the sliding direction. EDS analysis showed that delamination was cohesive, which occurred within W-DLC coating layer, rather than at the boundary between W-DLC coating layer and Cr interlayer. There were few micro-particle pullouts found near PL (pitch line) and HPSTC (highest point of single tooth contact).
The next inspection was at 74k stress cycles at low load and high speed (Step 2). More micro-particle pullouts were found and delamination observed when sliding is involved. The delamination was shown in Figure 3 at LPSTC and Figure 4 at HPSTC. Sliding direction is also shown in the Figures as white arrows.

Further progression of delamination accumulated under high load and low speed for another 6475 stress cycles (Step 3). Due to the higher contact stresses and thinner hydrodynamic film, the size of delamination increased from less than 10µm to about 100µm near LPSTC and 40µm near HPSTC. The growth of delaminated area was accelerated under higher stress and coalescence of neighboring micro-particle pullouts. Cr interlayer and substrate exposure was evident for these delaminated areas, as shown in Figure 5 and Figure 6.

The polishing of the coating took place at a slower rate in comparison to delamination degradation. After 154.5k stress cycles accumulated, the edges of micro-particle pullouts and delaminated area were smoothed (Figure 7). These smoothed edges gave less opportunity for further delamination of the coatings. After 154.5k stress cycles accumulated, coating was polished with a significant reduction of Sa, especially near HPSTC. The mating gear surface was polished after few stress cycles and remained the same during the rest of the test.

4. SURFACE FINISH ANALYSIS
Stylus profilometry was used to measure surface topography at each interruption of the test. The arithmetic mean deviation of the surface, Sa, is summarized in Figure 9. The increase of Sa was due to micro-particle pullout and delamination of the coatings. After 154.5k stress cycles accumulated, coating was polished with a significant reduction of Sa, especially near HPSTC. The mating gear surface was polished after few stress cycles and remained the same during the rest of the test.

5. CONCLUSIONS
Degradation of W-DLC coating is summarized as: micro-particle pullout and a combination of cohesive delamination and polishing wear.

ACKNOWLEDGMENT
This work was supported by the US Department of Commerce, NIST Advanced Technology Program, cooperative agreement number 70NANB3048, Dr. R. W. Bartholomew, ATP program manager.

REFERENCES