Study DLC coating influence on lubrication regime transition

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1. Introduction

Most of the mechanical components in an automotive engine operate under mixt or hydrodynamic lubrication regime. Tribology tests carried out on DLC coatings are often done in boundary lubrication conditions, which are nice to describe wear mechanisms but that do not allow having the best information related to friction reduction in an engine. To attempt to understand friction reduction by applying a DLC coating, friction tests were done using a cylinder on flat linear alternative configuration, with parameters allowing observing the transition between different regimes.

2. Experiment and results

A linear cylinder on flat alternative tribometer was used to study the evolution of friction coefficient with the relative speed between samples. In the study, the 4 combinations of DLC coated and uncoated steel surfaces were tested. For all these tests, the tribology contact is partly immersed ina commercial SAE 5W30 additivated oil. The motion is obtained using an eccentric system rotating at 300 rpm, resulting in a track length of 10 mm and a maximum speed of 160 mm/s. For each couple of materials, the test is decomposed in 2 phases. A first phase is carried out at 110°C, allowing boundary regime, to make the running in of surfaces. At the beginning and at the end of the 18000 cycle running in period, fast records of data allowedstudying the friction coefficient as a function of the instantaneous speed. After the running in period, the system is cooled down to room temperature. The increase of the oil viscosity allowed making some short tests in a different lubrication regime than during running in. After test, the surfaces were characterized using AFM and optical microscopy, inside and outside the friction track on each sample, to determine the roughness and its evolution.

The results show that at the initial stage of running in, all the 4 combinations of surfaces behave in boundary lubrication. The 3 material combinations having steel in the contact show the same friction coefficient while the DLC/DLC contact shows a 25% lower friction coefficient. At the end of running in period, the friction remains in boundary regime for the 3 combinations containing steel. In the case of DLC/DLC contact,the evolution of friction coefficient with speed shows 2 parts. The first part, up to 35 mm/s operates in boundary lubrication with a friction level similar to the 3 other couples. Beyond 35 mm/s, the friction of the DLC/DLC contact shows a behavior typical of mixed regime. At 160 mm/s, the friction coefficient is half of the ones for the contacts containing steel.

After cooling down the oil, all the contact containing steel operate in the mixed regime from 17 to 160 mm/s, while the DLC/DLC contact operates in mixed regime up to 60 mm/s and in hydrodynamic up to 160 mm/s. Because of the shifting in the regime transition, the friction coefficient at 80 mm/s is decreased of 25% when one surface is DLC coated compared to the steel/steel pair, and the friction coefficient of the DLC/DLC is decreased of 80%

AFM examination of surfaces show that the roughness of steel mirror polished samples has increased from Ra=0.01 µm to values higher than 0.03 µm The roughness increase is associated to the formation of anti-wear tribofilm and fine scratches in the motion direction. On the coated samples, the roughness measurements show a strong decrease of roughness on the cylinders from Ra=0.03 to less than 0.01 µm. The surfaces appear very smooth. On the flat DLC coated sample, the roughness has not been changed by the friction test.

3. Conclusions

The friction tests in this study clearly show some differences in roughness evolution of polished surfaces depending on the fact they are DLC coated or not. The general trend indicates that the roughness of mirror polished steel surfaces increases, because some small scratches appear along the friction direction and because of the growing of antiwear tribofilm. When a DLC coated surface is submitted to wear, its roughness decreases a lot in the friction area. No tribofim island is observed on the DLC coated surfaces, contrary to the behavior of a metallic surface. Due to the evolution of the topography of surfaces, the transition of lubrication regimes are shifted, in accordance with roughness evolution. The main role of DLC coatings seems to allow the surfaces to be even more polished in an addtitivated oil, after use, contrary to metallic surfaces.

Friction gains on DLC coated tappets are mainly a matter of topography evolution. This also means that the fabrication of the part is important. A rough DLC coated surface will take more time to obtain a low friction coefficient and the counterpart may also be damaged. Waviness of the surface of parts may also be detrimental by increasing the local contact pressure.