Tribological properties of laser textured and DLC coated surfaces with solid lubricants

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Abstract

Hydrogen free diamond-like carbon coatings (DLC), i.e. tetrahedral amorphous carbon (ta-C) films, have high hardness and low coefficient of friction at ambient temperature and humid conditions. However, the coefficient of friction and wear rate in sliding contacts against steel surfaces increase severely at elevated temperatures. Adding solid lubricant into micro-reservoirs produced by Laser Surface Texturing (LST) has been reported to decrease the coefficient of friction of sliding surfaces. In this study, incorporation of MoS_2 and WS_2 solid lubricants onto laser textured and ta-C coated steel surface by burnishing was demonstrated to provide improved tribological properties such as low friction and high wear resistance at elevated temperature with an extended lifetime of the surfaces.

Introduction

Diamond-like carbon (DLC) films have been of interest due to their unique mechanical, chemical and tribological properties. Hydrogen free tetrahedral amorphous carbon (ta-C) films have high hardness and low coefficient of friction at ambient temperature and humid conditions. However, these tribological properties become remarkably deteriorated at elevated temperatures.

Solid lubricants are extensively used for reducing friction and wear in severe conditions, as in vacuum and high temperatures, where fluid lubricantion is not possible. Transition metal dichalcogenides (TMD) such as molybdenum disulphide (MoS_2) and tungsten disulphide (WS_2) are well known for their lubricating behavior [Winer, 1967].

Surface texturing as a method to improve the tribological properties of mechanical components is already well known for the last decade [Etsion, 2005]. The fundamental idea of LST is the controlled preparation of small dimples or grooves to act as lubricant reservoirs.

Solid lubricant addition onto surface micro-pits produced by LST has been reported to decrease the coefficient of friction of sliding surfaces [Rapoport *et al*., 2008]. The LST increased significantly the wear life of a burnished solid lubricant layer when compared to a non-textured surface.

Attempts of improving tribological properties of hydrogenated DLC by surface texturing have been reported [Dumitru *et al*., 2003] but no solid lubricants have been utilized in these studies.

The aim of this work was to improve the tribological properties of ta-C films at elevated temperatures by MoS_2 and WS_2 addition on LST surfaces.

Materials and Methods

Polished stainless steel (AISI 316, surface roughness less than 0,01 µm) disks were laser surface textured by picosecond laser. Dimples of 50 µm diameter and 5-10 µm depth with a spatial period of 50 µm yielding a dimple density of 28% were processed on the whole substrate surface.

LST steel substrates were coated with 1 µm thick ta-C film in DIARC filtered cathodic arc coating equipment.

MoS_2 and WS_2 solid lubricants were added on separate ta-C coated LST surfaces by burnishing technique using commercially available powders with an average particle size less than 2 µm. The burnishing process was done in lab conditions by applying a sliding pressure with a hard plate to the powder against the sample surface.

The tribological experiments were carried out by using a pin-on-disc (POD) tribometer developed at VTT. Tests were carried out with a sliding velocity of 0.05 m/s and a normal load of 10 N. At room temperature, 2 N load was used to avoid high Hertzian contact pressures at the beginning of the sliding. Stainless steel (AISI 316) spheres with 10 mm diameter were used as a counter body. In order to study the tribological properties of the samples at elevated temperatures, test temperature was varied from ambient room temperature to 350°C. Temperature steps were room temperature, 100°C, 200°C, 250°C, 300°C, and 350°C. The test was performed so that the temperature was increased into the next step after every 30 minutes of sliding and stopped when the coefficient of friction (COF) started to oscillate and increase remarkably. The sliding track was not changed between the different steps. COF for every temperature step was calculated as an average value of COF acquired during the test time of 10-30 minutes. As a reference, flat ta-C sample without any solid lubricant addition was also tested in the same manner.

Results

LST treated steel substrate resulted in a surface with evenly distributed dimples. Only small, approximately a few hundred nanometer high dimple bulges, which were removed after a short post-polishing process, were formed. After the coating process, the LST top surface had a whole ta-C film while the rough surfaces of the dimple bottoms were only partially coated.

Fig. 1 shows SEM images of burnished solid lubricants on ta-C coated LST surfaces. In the burnished surfaces, the dimples were filled with powder and also a few microns thick solid lubricant layer was formed on the areas around the dimples. Both lubricants were noticed to be rather adhesive on ta-C thus the burnishing method was noted to be a feasible method.

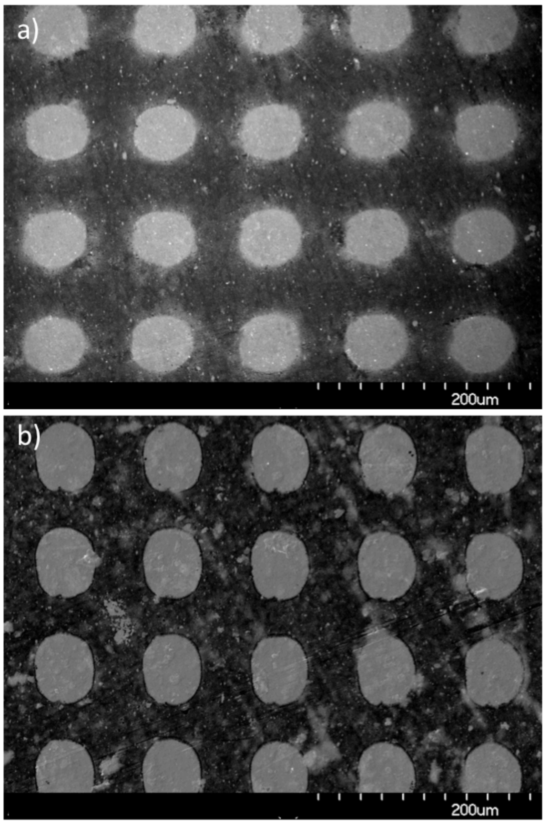

Figure 1. Burnished a) MoS_2 and b) WS_2 on ta-C coated LST steel surface.

The average COF values for ta-C coated LST surfaces with solid lubricants at different temperatures are shown in Fig. 2.

Burnished MoS_2 resulted to oscillation of COF values at room temperature (0.15-0.25). At 100°C, friction and oscillation decreased significantly. Lowest friction values of 0.02 was at 250°C but already at 300°C values increased and began to oscillate. At 350°C, friction increased severely and the coating broke down.

Burnished WS_2 had lower and more stable coefficient of friction than MoS_2 at room temperature (0.15) and COF decreased even further at 100°C. Interestingly the lowest coefficient of friction was approximately 0.05 at 300°C. At 350°C, the friction curve started to oscillate and slowly crept upwards as sliding continued, which indicated that the temperature was too high for WS_2 to operate properly. It seems that WS_2 addition provided better protection for ta-C at higher temperatures than MoS_2.

The reference ta-C film showed low friction values at ambient temperature but already at 100°C COF increased dramatically and the coating broke down after couple of minutes.

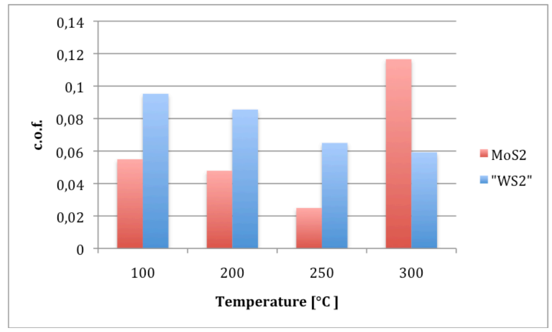

Figure 2. The average coefficient of friction values for ta-C coated LST surfaces with MoS_2 and WS_2 addition at different temperatures.

Discussion

The present study demonstrates possibilities for enhancing the tribological properties, such as low friction and wear resistance, of ta-C type DLC coatings in sliding contacts by a combination of laser surface texturing and solid lubricant.

Results showed that MoS_2 and WS_2 addition by burnishing did not improve the tribological properties of ta-C at room temperature but already at 100°C both solid lubricants provided a good protection for ta-C by reducing coefficient of friction remarkably compared to bare ta-C coating. It should be noted though that the solid lubricants used here would most probably oxidize if exposed to elevated temperatures for longer periods. This might have detrimental effect on their tribological properties.

Acknowledgements

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