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Tribological performance of fs-laser-induced periodic surface structures on titanium alloy against different counterbody materials using a ZDDP lubricant additive

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In this study the so-called laser-induced periodic surface structures (LIPSS, ripples) were produced on titanium alloy (Ti6Al4V) surfaces upon scan processing in air by a Ti:sapphire femtosecond (fs) laser. The tribological performance of the resulting surfaces was qualified in linear reciprocating sliding tribological tests (RSTT) against balls made of different materials (100Cr6 steel/Al_2O_3/Si_3N_4) using different oil-based lubricants. The admixture of the additive 2-ethylhexyl-zinc-dithiophosphate (ZDDP) to a base oil containing only anti-oxidants and temperature stabilizers disclosed the synergy of the additive with the laser-oxidized nanostructures. This interplay between the laser-textured sample topography and the local chemistry in the tribological contact area reduces friction and wear.

Keywords: lubricant additives, laser-induced periodic surface structures (LIPSS), wear; friction

1. Introduction

Laser-induced periodic structures (LIPSS, ripples) generated by ultrafast (fs>) laser technology proved to be a successful strategy to improve the tribological properties of titanium alloys [1]. Additionally, it has been speculated that the positive effect of the LIPSS may be attributed to the presence of the additive ZDDP [3]. These additive molecules could cover the laser-treated surfaces and therefore prevent a direct contact of the tested metals. In this work a specific emphasis is laid on the disclosure of the relevance of some specific anti-wear additives. By replacing a commercial engine oil (VP1) by an admixture of its base oil (VPX) with a single additive -here, the anti-wear additive (2-ethylhexyl zinc dithiophosphate, RC 3180) - its crucial role has been specifically addressed. Moreover, since the oils and additives are optimized for metallic (steel) surfaces, by varying the counterbody material, the role of the surface chemistry is further elucidated.

2. Methods

Low spatial frequency LIPSS (LSFL type) were uniformly processed by Ti:sapphire fs-laser pulses (30 fs, 1kHz, 0.11 J/cm^2) on polished Ti6Al4V titanium alloy grade-5 commercial samples. The processed LIPSS revealed periodicities of 620±80 nm along with height modulation depths of ±150 nm. The tribological performance of the surfaces [reference (polished) vs. fs-laser-processed (LSFL-covered)] was determined in linear reciprocating sliding tribological tests against 100Cr6 steel, Al_2O_3 and Si_3N_4 balls as counterbodies in two different lubricants [VPX oil and VPX oil + 0.5% of an anti-wear commercial ZDDP additive]. After the RSTT (normal force 1.0 N, stroke 1 mm, frequency 1 Hz, cycles 1000) for measuring the CoF, the wear tracks were characterized by Optical Microscopy, Scanning Electron Microscopy, and 3D Confocal Profilometry.

3. Discussion

For the specific testing conditions here, a reduction by a factor of 4-5 for the coefficient of friction and by a factor bigger than 2500 for the wear volume was observed in RC 3180-additivated VPX oil, while the tribological tests against 100Cr6 balls showed no beneficial influence of LSFL-covered surfaces with VPX oil lubrication (see Figure 1). This clearly evidences the previous speculation that only the admixture of the specific ZDDP molecules account for the reproduction of the beneficial tribological behavior on the laser-processed Ti6Al4V surfaces.

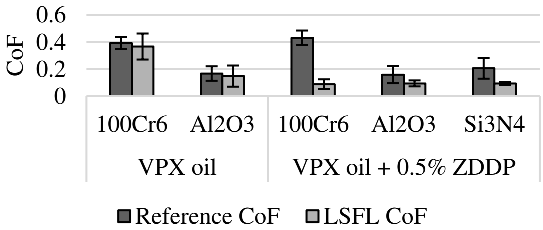

Figure 1: Mean values and standard deviations of the coefficient of friction (CoF) corresponding to the entire RSTT.

Additionally, no significant influence of the counterbody material (metal vs. ceramics) was observed (Figure 1), thereby implying that the positive effect is mainly caused by the presence of the 2-ethylhexyl-zinc-dithiophosphate molecules in the lubricant along with a nanostructured and oxidized layer on the laser-processed surfaces. The interplay between the sample topography (featuring an enlarged surface area and a confinement of the lubricant) and the local chemistry in the tribological contact area (via formation of a protective surface layer on the LSFL) prevents a direct contact of the two sliding bodies, finally resulting in reduced friction and wear.

4. References

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