Dust resilient polymer-based bearing coatings for Lunar and Mars application

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Introduction: As NASA seeks to expand its exploration to Moon and Mars, novel materials with advanced tribological characteristics at extreme conditions have to be introduced to guarantee the functionality of the exploration systems such as rovers and robotic rotorcraft landers. Dust is the number one concern in returning to the Moon, Apollo 16 Astronaut John Young, July 2004 [1]. The Moon is covered by large amounts of dust particles, called regolith, which could cause serious problems for tribological components on the Moon [2]. Many studies have been carried out on lunar dust abrasive wear for different tribo-pairs [2]. Because Mars and the Moon have large temperature spans during day and night, in addition to the abrasive study, the effect of temperature should be taken into account to achieve a better understanding of dust mitigation strategies. In Matsumoto's study [2], the tested bearing surfaces (such as MoS2 coating, Ti-6Al-4V alloy, A6061 aluminum alloy, and 440C SS) were worn away easily by dust particles; however, a PTFE-based coating showed high wear resistance in abrasive dust condition.

This study reports on tribological solutions for extreme temperature ranging from -150 to 110 °C combined with abrasive sand/dusty environment, which simulates extreme operating conditions that bearing materials in Moon and Mars environment. To this end, the tribological performance of PEEK-based and ATSP-based polymer coatings [3] were evaluated and it was demonstrated that ATSP-based coating vs. ATSP-based coating and PEEK-based coating vs. PEEK-based coating have excellent tribological performance, sustaining a low coefficient of friction (COF) and low wear. Additionally, the micro and thermomechanical properties of the coatings were measured and correlations were made with tribological performance.

Dust Simulant and Sample Preparation: ATSP powder (mixture of CB2+AB2 oligomers) was blended with 5% PTFE and the PEEK (1704 PEEK/PTFE®) with 20% PTFE lubricant additives and then deposited on the sand blasted Aluminum alloy plates and Titanium pins using electrostatic spray deposition (ESD) method. Lunar dust simulant was purchased from CLASS Exolith Lab and sieved into two particle sizes, namely less than 32 μm that is referred to dust and between 32-125 μm that is referred to sand.

Experimental Procedure: The experiments were carried out using a curved pin-on-disk configuration that could simulate a bushing's line contact. Test temperature was varied between -150 to 110 °C to account for the effect of temperature and the experiments were performed under the load of 5N (Hertzian contact) and speed of 0.25m/s (270rpm) under N_2 environment. Different tribo-pairs were used to simulate polymer vs. polymer, polymer vs. metal, and metal vs. metal tribo-contact to investigate the effect of coating deposition on each substrate as a dust mitigation solution.

Experimental Results: Figure 1(a) show the evolution of in-situ COF vs. sliding time for different tribo-pairs namely ATSP/PTFE vs. ATSP/PTFE (A on A), PEEK/PTFE vs. PEEK/PTFE (P on P), bare Ti vs. ATSP (Ti on A), bare Ti vs. PEEK/PTFE (Ti on P), and bare Ti vs. bare Al (Ti on Al) under partial dust (PD) environment (dust coverage density: 5g/m^2). The in-situ COF shows a run-in behavior followed by a steady-state condition. Overall, the in-situ COF shows a similar trend for all the tribo-pairs except for the Ti on Al tribo-pair where high fluctuation and sudden spikes could be observed in the COF due to micro scuffing. This indicates the harsher interface once the tribo-pairs are used in their as-received state (i.e., uncoated).

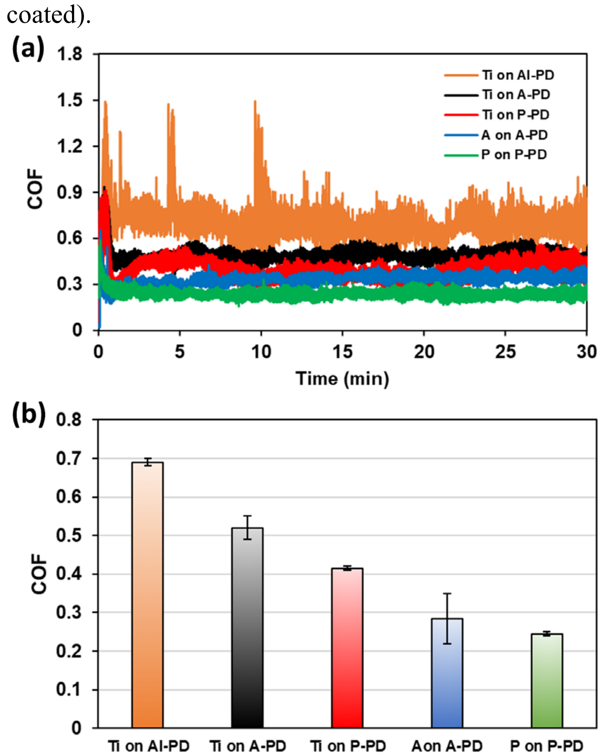

Figure 1. Experimental results showing (a) the in-situ COF and (b) average COF at the steady state period.

To resolve the problems with Ti on Al tribo-pair, the Al disk was coated with ATSP and PEEK-based polymers at the first step and as seen in the Figure 2, there was no indication of micro scuffing, and the fluctuation in COF was significantly reduced as well. The further improvement was achieved by depositing the coating on both Ti pins and Al disks with the same polymers to obtain a polymer on polymer sliding. As shown in the Figure 1, the COF was further reduced and in-situ COF achieved a better steady-state condition compared with the other tribo-pairs. Figure 1(b) show the summary of average COF values calculated. A continuous decrease in COF happened by depositing the polymer coating on the Al disks and thereafter the Ti pins. Therefore, the polymer on polymer sliding contact showed the lowest COF and the maximum COF occurred for uncoated Ti against uncoated Al samples.

Figures 2(a-f) show the SEM/EDS images of the worn surfaces of the disk samples after the experiments under PD condition with the tribo-pairs Ti on Al, Ti on A, Ti on P, A on A, and P on P, respectively. As shown in Figure 2(a) of the Al surface, the micro scuffing and abrasive wear are the main wear mechanisms caused by metal on metal contact as well as entrapped dust particles. From Figure 2(b, c), the ATSP and PEEK coatings only showed the dust accumulation and sporadic dust embedment on the coatings. Compared with PEEK coating, the ATSP coating showed more resistance to dust accumulation. As seen in Figures 2(d, e), once the Ti pins were coated with the selected polymers, the problem with dust accumulation and embedment was resolved but the coatings were under higher intensity of abrasive wear instead. Compared with ATSP, dust caused more abrasion on the PEEK where deep wear grooves could be identified. As it was discussed, the majority of the surface of the coating was covered with embedded and distributed dust particles. In order to verify this observation, the EDS mapping was taken on the ATSP coating surface and is shown in Figure 2(f). As it is demonstrated by the green color that is indicative of Si element due to dust particles, the majority of the sur-face is covered by dust which complements the observations through the SEM.

In summary, the deposition of the polymer coatings on the Ti and Al samples was shown to be an efficient way to reduce the COF and dust/sand mitigation. Once the polymer coating was deposited on both pin and disk substrates, the COF was reduced up to 65% and the dust and sand accumulation at the interface was significantly reduced as well. Compared with PEEK coating, the ATSP coating showed higher abrasive resistance and the COF was nearly the same in most conditions.

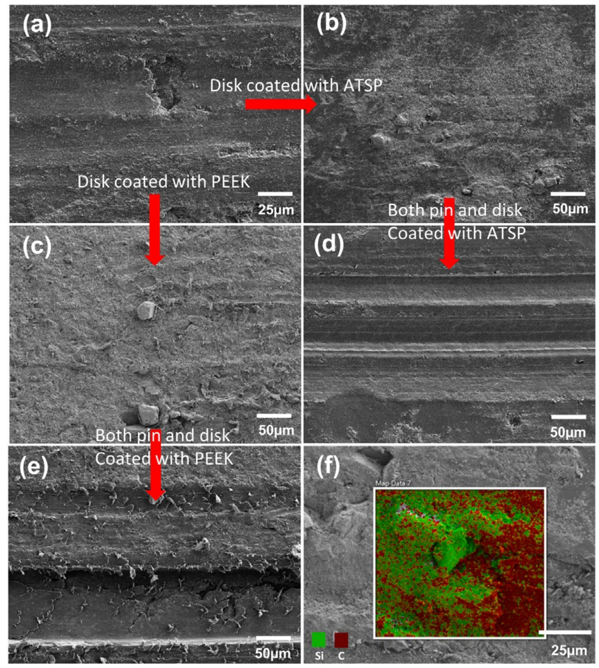

Figure 2. SEM images of the worn surfaces of the disks after pin on disk experiments of (a) Ti on Al (b) Ti on ATSP, (c) Ti on PEEK, (d) ATSP on ATSP, and (e) PEEK on PEEK coatings. (f) The EDS mapping showing dust embedment and distribution on the ATSP coating.

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