Fretting Corrosion Analysis of Ti-Mo-Zr-Fe (TMZF®) and Gas Atomized Dispersion Strengthened Co-Cr-Mo (GADS) Alloys Under Shot Peened and Shot Peened, Cleaned and Passive Conditions

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Introduction: Mechanically assisted corrosion is a continuing concern with all metallic implant materials. When mechanical abrasion occurs, the passive oxide film is disrupted and this can accelerate the corrosion process. Factors such as mechanical, electrochemical, geometrical, material and solution conditions may all influence the behavior. In this study, two novel alloys, Ti-Mo-Zr-Fe (TMZF) alloy (Stryker Orthopaedics, NJ) and gas atomized dispersion strengthened (GADS) Co-Cr-Mo alloy (Stryker Orthopaedics, NJ) are investigated using a pin-on-disk test for their fretting corrosion behavior when abraded against one-another. The effect of load and potential on material combinations of TMZF and GADS are investigated in phosphate buffered saline (PBS). Also, the surface treatments of shot peening, and cleaning and passivating are investigated in terms of the fretting corrosion response to load and potential.

Methods: For this experiment, the test samples consisted of a flat circular disk and a cone-shaped flat bottom pin made of TMZF, GADS and a CoCr (ASTM F-1537) alloys. Both pin and disk samples were fabricated by Stryker Orthopaedics. Along with being shot peened some of the samples were also cleaned and passivated to investigate if non-cleaned and passivated surfaces demonstrated differences from the clean and passive condition. Shot peening, cleaning and passivation were performed using similar process parameters that hip implants manufactured from these alloys commonly undergo during regular production. The test areas of pin and disk were controlled by using an acrylic coating material to expose only the contact region to the solution environment. All experiments were performed at room temperature in PBS (pH 7.4), at 50 µm displacements and a frequency of 2.5 Hz. During fretting, the load, coefficient of friction (COF), motion and currents were continuously monitored and recorded for all experiments. Two different experiments were performed: a load test and a voltage test. Load tests were conducted by varying the normal load from 0.5 N to 30 N at a fixed potential of 0 V (vs Ag/AgCl) for TMZF/GADS, Clean and Passive TMZF/GADS and Clean and Passive TMZF/CoCr couples. Repeated tests to the same test area were performed at different load magnitudes without separating the pin and disk surfaces. The voltage test varied the potential from -700 mV to +700 mV (in 200 mV increments) at a fixed load of 6 N for all couples. For each test, the data analysis included calculation of the average fretting current density, the fretting coefficient of friction (COF. Post-test surface characterization of the pin and disk samples were performed using Scanning Electron Microscopy (SEM) for area measurement and damage assessment. Where appropriate, statistical analysis of the results was performed using ANOVA methods.

Results: *Loading Tests:* For all material combinations, COF (Fig. 1a) starts at a high value and drops to about 0.2 to 0.3 and stays constant at the higher stresses. The average fretting current density (Fig. 1b) increased with increasing loads to a maximum between 1.2 and 1.4 mA/cm^2 and then dropped as significant sticking occurred between pin and disk. Statistical analysis showed small differences in COF and fretting current density with stress ($P < 0.05$).

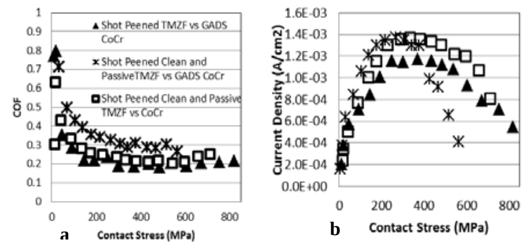

Fig 1: a. COF v contact stress for all groups. b. fretting current v stress.

Potential Effects: COF varied with potential as seen in Fig. 2a, rising and falling as voltage increased. Fretting current densities for all three material couples were similar and highly dependent on voltage (Fig. 2b). Fretting current onset potential was about -400 mV vs Ag/AgCl for all material couples and the current densities rose with voltage in a linear fashion. These results are consistent with what has been reported for Ti-6Al-4V/Co-Cr-Mo couples[1,2].

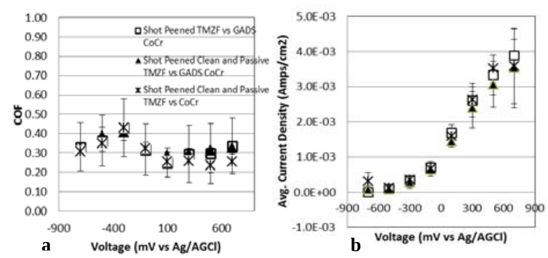

Fig. 2: COF and fretting current density vs potential.

Discussion: These results show that TMZF/GADS fretting corrosion is similar to that seen in TMZF/CoCr-Mo and Ti-6Al-4V/Co-Cr-Mo couples in terms of load and voltage effects[1,2]. The current versus voltage plots show that the couple's behavior is governed primarily by the GADS properties. The COF also is a function of the applied potential ($P<0.05$). COF and current vs load responses are also similar to Ti-CoCr interactions seen previously. The pin-on-disk fretting corrosion test can capture detailed mechanical, electrochemical and structural interactions present and provides an excellent means to evaluate these processes.

Conclusions: These experiments investigated the effects of load and potential on the COF and current density during the fretting of TMZF-GADS combination with different surface treatments. In this test model, the fretting corrosion of TMZF-GADS combinations was affected by the normal load and potential and was no different from that seen for TMZF/ Co-Cr-Mo and Ti-6Al-4V/Co-Cr-Mo couples.

References: 1. Swaminathan and Gilbert. Biomaterials. 2012; 33:5487-5503. 2. Swaminathan and Gilbert, JL, J Biomed Mat Res – Part A, in review **Acknowledgements:** Supported by Stryker Orthopedics.