Instrumented Fretting Corrosion Analysis of CoCr/Ti and Ti/Ti Metallic Couples

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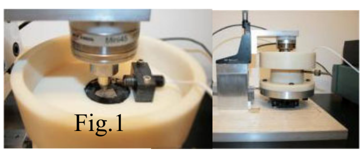
Statement of Purpose: Fretting corrosion of metallic biomaterials, including those used in modular interfaces of total joint replacements, spinal devices and even cardiovascular stents is increasingly a major concern.[1, 2] The increasing use of modularity in hip, spinal and other metallic implants, together with combination of different metal alloys necessitates a need to assess their fretting corrosion performance. However, there is a lack of test methods that can control, monitor and assess the mechanical and electrochemical processes present at the metal-metal fretting interfaces. A fretting crevice corrosion test instrument was developed and the effect of potential and normal load on fretting corrosion of Ti6Al4V/Ti6Al4V and Ti6Al4V/CoCrMo combinations was studied. The preliminary results are presented here.

System Description: The design of the fretting-crevice corrosion system requires combination of several different actuation, sensing and control elements that relate to the mechanics and electrochemistry of the system. The complete test system is shown in Fig.1. A piezoelectric actuator (Piezo-Jenna Systems, Germany) with a motion range of up to 140 µm is used for the motion control. A multi-axis load cell (MINI 45 F/T, ATI Ind Meas Inc.,USA) coupled to the vertical loading system is used to measure force and torque in all six directions. The nominal contact stress and the friction coefficient can be calculated from load cell data at any instant during oscillatory fretting motion. The system also includes a high resolution (1 µm) contact DVRT (Microstrain Inc., USA) to monitor relative displacement between two sample surfaces, and electrochemical control is by a 3-electrode potentiostat. Data acquisition tasks are performed using LabView 9.0.



Materials and Methods: Test materials consisted of flat-bottom discs connected to the potentiostat and cone-shaped pin with flat bottom of diameter 0.5 mm made from wrought CoCrMo alloy or Ti6Al4V alloy connected to the load cell. Fretting corrosion tests were performed using the system described above by either varying the sample potential (-1 V to 0.8 V vs. Ag/AgCl) at fixed loads (5 N) and motion conditions, or varying the normal load (up to 20 N) at fixed potentials [-0.1 V (Ti6Al4V/Ti6Al4V) or 0 V (CoCrMo/Ti6Al4V)] and motions, and simultaneously measuring both electrochemical aspects (fretting currents) and mechanical aspects (loads and coefficient of friction (COF)). All tests were done in phosphate buffered saline solution (pH 7.4) at fixed fretting amplitude (50µm) and frequency (1.25 Hz). The average and standard deviation of fretting currents and COF (sliding) were calculated. Two trials were performed for each test and with additional trials (under way) statistical analysis will be performed using ANOVA methods ($p<0.05$ is significant).

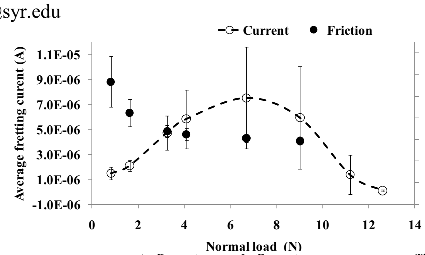


Figure 2.Average fretting currents and COF of Ti6Al4V/Ti6Al4V in PBS at varying normal loads (-0.1 V, 50 µm, 1.25 Hz)

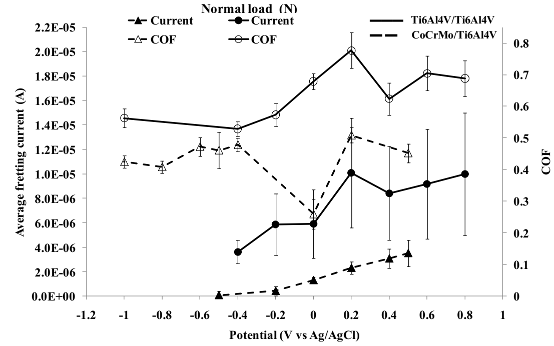


Figure 3.Average fretting currents and COF of Ti6Al4V/Ti6Al4V and CoCrMo/Ti6Al4V couple in PBS at varying potentials (5 N, 50 µm, 1.25 Hz)

Results and Discussion: Fig. 2 shows that increases in normal load up to 7 N increased the fretting corrosion currents (up to 7 µA) of Ti6Al4V/Ti6Al4V due to increased disruption of the oxide film. However, at higher loads (> 7N) little variation is seen in fretting currents. Due to system compliance, increased normal loads will tend to reduce the overall motion magnitude as increased sticking friction occurs. From the data, the minimum normal load required to initiate fretting corrosion for this couple must be less than the lowest load applied in this study (0.8 N [4 MPa nominal stress]). Fretting currents of up to 1.2 µA was seen for CoCrMo/Ti6Al4V (data not shown). Also, from Fig. 2 there is a systematic variation in sliding COF values with load where higher loads resulted in lower COF (varying between 1.1 and 0.6). Fig. 3 shows that surface voltage affects the average fretting currents (higher currents with more positive potential) and COF of both the couples, with Ti6Al4V/Ti6Al4V couple showing relatively higher values of current and COF over the potential range tested. This could be due to voltage-dependent changes in the oxide film structure and chemistry leading to differences in the interaction between surfaces.

Conclusion: The results show that fretting corrosion is affected by material combination, normal load and potential. In particular fretting currents increased with load and potential and COF decreased with load and varied with potential. Based on these preliminary results it can be said that CoCrMo/Ti6Al4V has higher fretting corrosion resistance than Ti6Al4V/ Ti6Al4V.

References: (1) Gilbert JL et al. JBMR B: 2009:88(1):162-73.
(2) Halwani et al. JBMR B: 2010:95B:225-238

Acknowledgements: Depuy Orthopedics Inc.