Tribocorrosion Behavior of a Low Carbon CoCrMo Alloy for Hip Joint Applications: Synergisms and Mechanisms

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Statement of Purpose: Metal-on-metal (MoM) bearings currently constitute about 35% of over 200,000 primary total hip replacement (THR) procedures performed annually in the US [1], yet there are increasing reports of adverse local tissue responses mediated by metal ions and wear debris generated by wear and corrosion of MoM THRs and surface replacements [2, 3]. In this study, it is hypothesized that synergistic interaction of wear and corrosion plays an important role in the degradation mechanism of a low carbon CoCrMo alloy.

Methods: Pins, 12mm diameter, machined from low-carbon CoCrMo rods (0.24 % carbon, ATI Allvac) articulated against a 28 mm diameter alumina ball in a specially designed pin-on-ball set up incorporating an electrochemical cell with diluted bovine calf serum (30 g/L protein) as an electrolyte [4, 5]. The flat surface of the pins was polished to a roughness of 9.4 ± 2.6 nm Ra using standard metallographic methods. The wear tests were performed using a normal load of 16 N with ball rotation of ± 15° at 1 Hz for 100K cycles Two series of tests were conducted: (1) under free corrosion potential (Ecorr) and (2) under potentiostatic conditions, at a fixed potential of -0.28V *vs.* SCE. Electrochemical impedance spectroscopy (EIS) measurements were taken before and after a test. Polarization resistance (Rp) was determined using the Randles EIS equivalent circuit. The total material loss (Kwc) was determined by 3-D profilometry and the loss due to corrosion (Kc) was calculated with Faraday's law.

Results: Under free corrosion potential conditions, the CoCrMo potential decreased from -300 to -600 mV, indicating an increased corrosion tendency (Fig. 1a). The drop halted quickly, indicating stabilization. Under potentiostatic conditions, the current exhibited a sudden increase at the onset of sliding, followed by marked fluctuations during the sliding process (Fig. 1b).

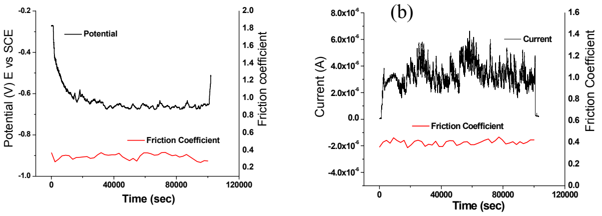

Fig. 1.(a) Potential and friction coeff, evolution under free potential conditions. (b) Current and friction coefficient. evolution under potentiostatic conditions.

The friction coefficient was fairly constant for both conditions. The polarization resistance (Rp) was higher after sliding than before sliding ($p = 0.035$) (Fig. 2).

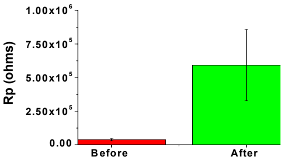

Fig. 2. Polarization resistance before and after sliding

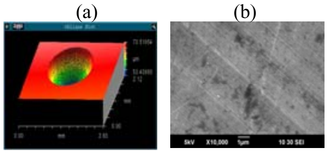

Fig. 3. (a) Wear scar. (b) Worn surface under potentiostatic conditions

For both tests, the wear scar had the expected spheroidal shape (Fig. 3a). Examination by SEM of the wear scar revealed a patchy tribolayer (Fig. 3b). Under potentiostatic conditions, the mass loss due to corrosion (Kc) accounted for the majority of the total mass loss (Kwc), as shown in Fig. 4(a), where Kw, the mass loss due to wear, equals Kwc - Kc.

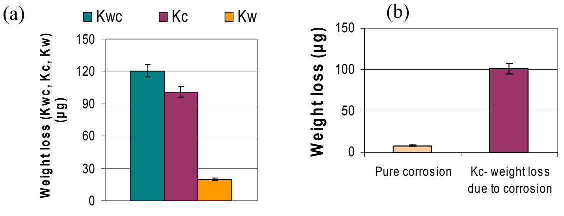

Fig. 4. (a) Weight loss distribution under potentiostatic conditions for LC-CoCrMo alloy. (b) The weight loss due to corrosion (Kc) is compared with pure corrosion [6].

Discussion: The shift to a more cathodic potential (Fig. 1a) suggests potentially more susceptibility to corrosion during sliding. Despite the lack of an overall current increase during sliding (Fig. 1b), an increase in polarization resistance after sliding (Fig. 2), and the formation of a tribolayer (Fig. 3b) that can be protective [3, 6], the amount of corrosion with sliding is markedly more than without sliding (Fig. 4b). The synergy ratio Kc/Kw of 5.2 indicates a corrosion-dominated wear mechanism [7], supporting our hypothesis. The current oscillations (Fig. 1b) presumably arise from the depassivation/repassivation corrosion kinetics of the surface, consistent with wear-enhanced corrosion. Synergism considerations are therefore important in understanding the release of wear debris and metal ions in metal-on-metal hip bearings.

References: [1] Bozic KJ et al., JBJS Am 2009;91:128-133. [2] Jacobs JJ et al., JBJS 2006; 88-A. [3] Wimmer MA et al., J Orthop Res. [4] Mischler S., Trib Int 2008; 41:573-583. [5] Mathew et al. ORS 2010, No: 2263. [6] Mathew et al. ORS 2011, accepted abstract. [7] Stack M. M., Wear 1997; 203-204: 474-488.

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