Accelerated Fretting and Corrosion Testing of Diffusion Hardened Oxidized Zirconium and Cobalt Chromium Molybdenum Modular Acetabular Liners

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INTRODUCTION *In-vivo* corrosion at the taper interface between modular CoCrMo acetabular liners and their mating titanium-aluminum-vanadium (Ti-6Al-4V) shells has been documented in the literature [1,2,3]. This can lead to elevated serum levels of cobalt and chromium [4]. To replicate taper corrosion *in-vitro*, ASTM F1875-98(2014) can be used as guidance for corrosion testing of modular femoral head tapers; however, no standard test method currently exists for the modular acetabular junction. Therefore, the study had two goals: develop a test method which caused similar corrosion damage to CoCrMo acetabular liners as that observed in retrievals, and compare the corrosion performance of modular acetabular liners made from CoCrMo and diffusion hardened oxidized Zr-2.5Nb (DH-OXZr). It was hypothesized that a modular liner made from DH-OXZr may mitigate the corrosion observed with CoCrMo liners.

METHODS CoCrMo and DH-OXZr acetabular liners (44 mm inner diameter, N=3 each) were manufactured using identical dimensions and surface finish to assess only the variable of liner material. The taper surface of the HD-OXZr liners was not oxidized. The liners interfaced with a Ti-6Al-4V acetabular shell (56 mm outer diameter). A fixture with a 56 mm hemispherical cavity, a defect with a depth extending 36° downward from the cavity rim, and a span of 120° per ASTM work item WK28883 (F3090-20) was created from acetal resin to support the acetabular shell and liner. The acetabular shell was pressed into the cavity, and the liners were impacted three times into the shells using a 0.907 kg drop weight from a height of 25.4 cm per ASTM F2009-20. The acetal resin fixture was supported such that the acetabular construct was at a 55° inclination angle to the load vector. The construct was surrounded by an acrylic cylinder, which was filled with a solution of Lactated Ringer's and hydrochloric acid to achieve pH of 3.5. A temperature controller and heat lamp were used to maintain the solution at 37° C during testing. The acetabular liners were loaded using a 44 mm diameter rounded acetal resin fixture at a rate of 3 Hz for 5 million cycles. The test setup is shown in Figure 1. A sinusoidal cyclic load of 389/3,892 N was used based on the maximum resultant *in vivo* hip force during stair descent, normalized to a 100 kg body weight [5]. After the completion of testing, solution was collected from each acetabular construct and analyzed for relevant ions using inductively coupled plasma mass spectrometry (ICP-MS). The concentration for each element was multiplied by the final solution volume to determine the mass in solution per ASTM F1875-98(2014). The element masses of the CoCrMo and DH-OXZr liner constructs were compared using a Fisher's F-test for variances and a Student's t-test for differences in means, with a confidence level of $\alpha = 0.05$. The liners were disassembled from shells, and the taper surfaces were characterized for the damage.

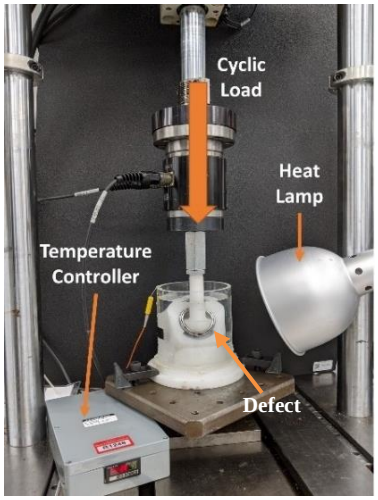
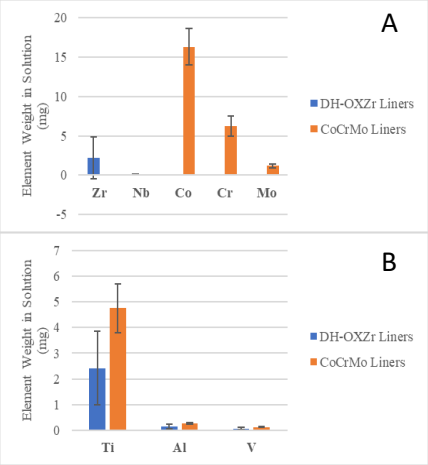


Fig. 1: Acetabular liner corrosion setup



RESULTS The results of the ICP-MS analysis are in Figure 2. The average values for Ti, Al, and V were greater for constructs with CoCrMo acetabular liners, although the differences were not statistically significantly different ($p > 0.05$). For total elements from the liner alloys (Zr+Nb vs Co+Cr+Mo), there was a statistically significant difference between the DH-OXZr liners (2.21±2.68 mg) and CoCrMo liners (23.71±3.79 mg) ($p = 0.001$). Discoloration was observed on both the liner and shell tapers for the CoCrMo constructs (Figure 3), primarily in the superior region based on the load vector direction. Minimal discoloration was observed on the DH-OXZr liners and shell after testing. Evidence of fretting at the contact interface between the shell and liner was visible for both liner materials.

DISCUSSION The mechanism for mechanically assisted crevice corrosion (MACC) between taper junctions in orthopedic implants is well documented in literature [6]. MACC depletes oxygen from the solution and makes solution highly acidic in nature. By using low pH or acidic solution from the start of the test, corrosion at the junction can be accelerated. DH-OXZr has been shown to reduce material loss and corrosion in femoral head tapers based on *in vitro* testing [7], but this is the first study to show the potential benefits for DH-OXZr acetabular liners. The material loss in solution and the discoloration on the surface of CoCrMo liners indicates that the test method can be used to examine both fretting and corrosion mechanisms for metallic acetabular liners.

Fig. 2: Graphs showing material mass loss in solution for acetabular shell elements (A) and acetabular liner elements (B).


Fig. 3: Discoloration and fretting on the liner (left) and shell (right) taper surfaces of a CoCrMo construct after fatigue testing.

SIGNIFICANCE As the use of modular metallic acetabular liners increases, a simplified test method that can replicate corrosion and fretting damage observed *in vivo* is needed to screen liners for material and design. The results of this study indicate that corrosion damage can be replicated on CoCrMo liners using a lowered pH, a large acetabular defect, and high load levels. DH-OXZr may result in reduced corrosion and material loss compared to CoCrMo liners.

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