Stripe Wear Analyses in Large-diameter Ceramic-on-Ceramic Bearings in Microseparation Simulator Mode

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Introduction: Alumina Matrix Composite (AMC) ceramic was introduced year-2000 as an alternate material to pure alumina (Al). In-vitro studies have presented improved performance for only the 28mm THR under microseparation (MSX) test mode [1]. However the literature lacks a detailed investigation of run-in wear, stripe formation and monoclinic content of AMC balls and cups, particularly the larger diameters now in demand. Therefore we compared AMC to Al ceramics by like-on-like pairings and also the 2 hybrid pairings. Our goals were to examine both materials under MSX conditions to better understand their tribological performance.

Materials and Methods: Like-on-like and hybrid pairs were diametrically matched over a range of tolerance for Al and AMC pairings (Table: 1). The ceramics were manufactured under trade names Biolox-forte™ and Biolox-delta™ (CeramTec Inc., Germany). The Al/Al combination was our control pairing. Our 'severe' MSX test mode was run on a orbital hip simulator (Shore Western Man. Inc) modified to produce a displacement up to ~2mm, using Paul load curve (max. 2Kn) run at 1Hz with alpha-calf serum (Hyclone®, Ogden UT) as bearing lubricant (10mg/ml).

Table: 1 –ceramic combinations using large diameter bearings (36mm)

Pairing #	Sample (N)	Cup Material	Ball Material
1	3	Al (forte™)	Al (forte™)
2	3	Al (forte™)	AMC (delta™)
3	3	AMC (delta™)	Al (forte™)
4	3	AMC (delta™)	AMC (delta™

Wear was determined gravimetrically up to 5Mc. Wear scars 'stripes' were inspected at every event and photographically logged. Serum was stored frozen for debris analysis under SEM. Post analysis of ball and cup involved: SEM and Raman spectroscopy for wear and monoclinic content with roughness measurements at the pole (0°) and stripe locations (75-90°) for the balls (1.1 and 5.0Mc).

Results - Wear: A wear stripe was observed on all balls and cups after the first 100K cycles. These grew in length and width over duration of study with Al/Al being the most prominent (Fig. 1). By 5.0Mc with this severe MSX test mode, the Al/Al pairing averaged highest at 1.53 mm^3/Mc and AMC/AMC averaged lowest at 0.24 mm^3/Mc. Hybrid combinations (Al/AMC; AMC/Al) had similar wear rates of (0.47 and 0.53mm^3/Mc respectively). Therefore the AMC/AMC exhibited a 6-times wear reduction compared to control, while AMC/Al and Al/AMC presented a minimum of 3-times reduction.

Monoclinic transformation within AMC: Tetragonal-to-monoclinic transformation was detected in all AMC samples at the two sites analyzed (pole (0°)) and stripe (75-90°) at 1.1 and 5.0Mc duration. Monoclinic content for the balls was greater at the stripe site (24%) than the pole (14%) at 1.1Mc however; at the end of study (5.0Mc) both sites had similar content, 27% and 23% respectively. The cups had same monoclinic content (~15%) regardless of location at 1.1Mc however at the end of study the pole location had a slightly higher monoclinic content than the stripe site, 22% and 19% respectively. In general for both ball and cup the pole compared to the stripe site showed a higher relative increase in monoclinic content over the duration of study, where on average the balls increased 71% and the cups increased 52% in monoclinic content.

Surface Roughness: Over both durations measured the pole roughness did not change from its original value (<10nm). In contrast the stripe site at 1.1Mc increased in roughness to a max. of 36nm (AMC/Al) and at end of study to a max. of 113nm (Al/Al), figure: 2. We investigated the relationship between ball stripe roughness and ball wear rate at end of study (5.0Mc) and found this to be linear (R^2= 0.9753, Fig: 3) this is the first time this relationship has been reported for these material combinations and simulation configuration.

Figure: 1 – Wear stripes (ink marked) at 5.0Mc representing a broad and deep stripe on the Al-ball (LHS) and a less significant stripe on the AMC (RHS).

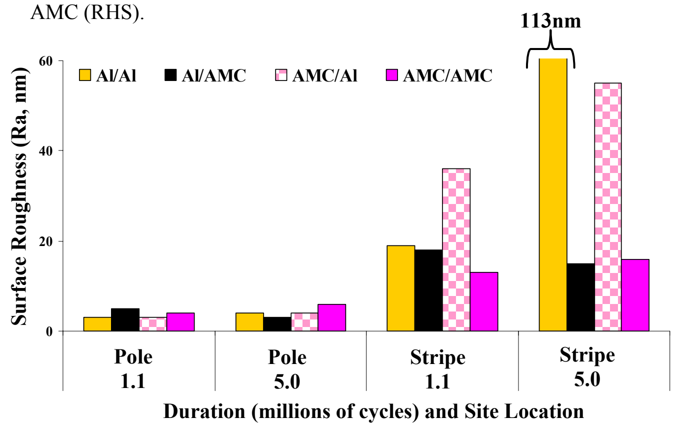

Figure: 2 – Ball roughness at two test durations (pole and stripe).

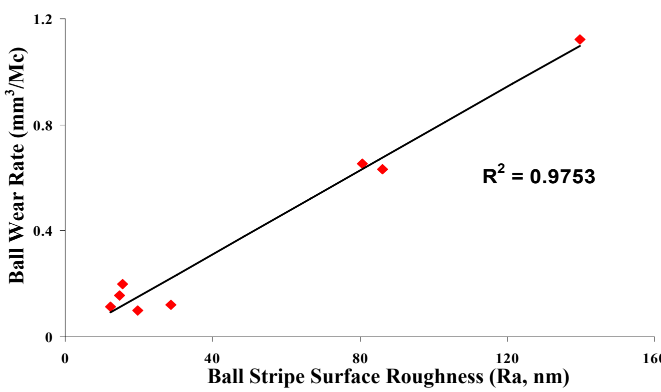

Figure: 3 – Ball roughness versus wear rate at 5.0Mc duration.

Conclusion:

We produced clinically relevant stripe wear phenomenon and wear-rates [2] in a detailed wear assessment of four ceramic combinations. Al/Al had the highest wear rate, the hybrid pairings reduced wear-rates by 3-fold compared to control. AMC/AMC had the lowest wear, a 6-fold reduction compared to control. Phase studies of AMC implants revealed greater monoclinic transformation at the equator (at arc 75-90°) where the stripe initiated. Surface roughness was highest in controls and the AMC/AMC paring had the lowest roughness of all. We found a linear relationship (R^2=0.9753) between ball roughness and wear rates, the first report for these materials and large diameter ceramic configurations.

References:

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