Introduction

While clinical reports have been encouraging for metal-on-metal (MOM) hip bearings, some adverse effects have been reported [1]. A puzzling phenomenon has also been observed in hip simulators wherein one or more MOM bearings revealed 2 to 9 fold higher wear than apparently ‘identical’ bearings [2,3]. This phenomenon we termed ‘breakaway wear’ (BA-wear) has yet to be investigated.

The most likely suspects for BA-wear include simulator malfunction, serum contamination, contact area spreading across and into the cup rim, cup deformation and metallurgical variations. In contrast, some studies have indicated that bearing diameter, diametral clearance and bearing roughness were the dominant factors in MOM wear [4]. This thesis would indicate that a group of MOM bearings with ‘identical’ geometrical tolerances and used with precision mounting should show similar wear patterns and consistent wear trends. Therefore, hypothesis #1 was that carefully matched MOM bearings with virtually identical geometrical tolerances would provide similar wear trends.

Classical lubrication theory predicts that high conformity will produce optimal conditions for fluid-film lubrication, thereby leading to low wear. [4]. It follows that bearings with higher initial wear (run-in) will possess greater effective conformity and hence show low steady state wear. Therefore, hypothesis #2 was that MOM bearings with the highest effective conformity would show the lowest wear.

Materials and Methods

Six 60mm, high-carbon Co-Cr bearings were matched for diametral clearance and sphericity (Comis Orthopaedics, UK). Diametral clearances ranged 234-240 microns, sphericity 6-12 microns and Ra <15 nm. The cups were mounted anatomically, inclined at 45° in an orbital hip simulator using the standard Paul load profile. Each station’s load-cell was calibrated before and after the study. The lubricant was diluted bovine-cafe protein (serum: 17mg/mL, ISO 14242-1). Test duration was 5Mc. Persistent biological contaminants were removed with a lint-free cloth. Serum samples were digested in hydrochloric acid and Co and Cr ions assessed using an ICP/MS (Weck Laboratory, CA).

Bearing roughness was measured at 0Mc and 5Mc using a white light interferometer (New View 5000, Zygo). Trends in developing cup and ball wear scars were mapped sequentially and areas calculated. Changes in radii of curvature and sphericity of the heads and cups were measured at 0Mc and 5Mc using a coordinate measuring machine (CMM, Mitutoyo). Approx. 200 points per part were measured within each wear scar and the data was converted into 3D solid surfaces (RapidForm® XOV, Q-Plus, CA) and geometries calculated. Standard equations for effective radius, maximum contact pressure, minimum film thickness and lambda ratio were calculated at 0Mc and 5Mc to estimate any changes in the lubrication conditions [4].

Results

No discoloured serum lubricant was encountered in this study and all cup wear scars were contained within the cup rim at the ending of study. In general, none of the femoral heads showed BA-wear with all heads producing less than 1.2 mm³ of total wear at 5Mc duration (Fig.1). These MOM wear rates were in the range of published data. Four out of the six MOM cups #1-4 (Non-BA-wear) showed low steady state (SS) wear to 5Mc duration (Fig.1, Table 1). The ion trends for MOM #3 duplicated the low wear obtained gravimetrically. Two of the six MOM cups showed BA-wear between 1 and 5Mc duration (BA-5, BA-6) (Fig.1). As a result, these bearings generated a 167% increase in overall wear rates. Cup BA-6 continued with elevated wear at 5Mc with no recovery. The ion trends for MOM #3 duplicated the higher wear obtained gravimetrically. For BA-5 and BA-6, cup wear represent 85% of the total wear. The non-BA MOM at 5Mc showed a 53% reduction in effective clearance (245 microns to 129 microns) and a 33% increase in effective radius (7.3m to 9.7m). In contrast, the wear scars on BA-wear MOM showed an 80% reduction in effective clearance (245 microns to 48 microns) and a 340% increase in effective radius (7.3m to 32m). Despite showing the highest wear at 5Mc, EHL analysis predicted that BA-5 and BA-6 had superior fluid film conditions at 5Mc, i.e. the lowest contact pressure (29 MPa), the largest film thickness (67 nm) and the largest lambda ratio (1.8) compared to the non-BA MOM.

Discussion and Conclusions

MOM bearings were studied with virtually identical tolerances and likely represents the most controlled MOM study to date. Despite this strict geometrical control, BA-wear was observed in approximately 30% of the MOM bearings. Therefore, hypothesis #1 was negated.

BA-wear trends appeared similar to previous MOM studies [2,3], producing a 3-fold wear increase above otherwise identical MOM bearings with 85% of the wear coming from the cup side. The reality of the BA-wear identified by weight-loss technique was confirmed by metal ion concentrations and area of wear scars. Although we did not identify the cause(s) of BA wear, we observed for the first time significant differences in test parameters between those bearings with normal wear and those with BA-wear behaviour.

Lubrication theory predicts that high conformity will promote low wear. However, the BA bearings produced the highest conformity and the highest wear, therefore negating hypothesis #2. Since these experimental findings appeared contrary to lubrication theory, there may be another confounding factor that negates the effect of bearing conformity.

Acknowledgements

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References


Table 1. Summary of average (head+cup) wear trends for all MOM.

<table>
<thead>
<tr>
<th></th>
<th>Total Run-In Wear (mm³)</th>
<th>SS Wear Slope (mm³/Mc)</th>
<th>Overall Wear Rate (mm³/Mc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-BA MOM</td>
<td>0.9 to 2.0</td>
<td>0.34</td>
<td>0.6</td>
</tr>
<tr>
<td>BA MOM</td>
<td>1.2 to 2.5</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Difference (%)</td>
<td></td>
<td>300% increase</td>
<td>167% increase</td>
</tr>
</tbody>
</table>

Figure 1. Cumulative volumetric wear for all acetabular cups and femoral heads over 5Mc. Note: BA-5 & BA-6 cups showed a 3-fold higher overall wear compared to rest at 5Mc.