1.2 Surface Analysis of Explanted Alumina-Alumina Bearings

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Abstract

The purpose of this study was to characterize wear stripes on explanted third generation ceramic-on-ceramic components. Macroscopy, light microscopy and scanning electron microscopy (SEM) was carried on the wear stripes to determine their extent and the material failure mechanism that led to their formation. The analysis shows that the wear stripes were formed through high stress, point contact of the head on the rim of the cup. This type of damage occurs due to microseparation of the head and cup during specific patient activities.

Introduction

Alumina ceramic-on-ceramic articulation is one of the best choices for hip joint bearings for young and active patients. Their low wear, less than 0.5 mm^3 per 10^6 cycles in vitro and the benign periprosthetic tissue reaction to the small amount of debris produced make them an ideal biomaterial for this application [1-3]. Even though the normal wear mechanism of these bearings is generally understood to be slight relief polishing; recently a number of wear stripes were reported on a series of explanted alumina-on-alumina components [4, 5]. The ceramics components concerned were part of a larger series of more than 1,500 successful implants done by mainly one surgeon at the Orthopaedic Hospital Sydney, Australia. The majority of the bearings were removed during a routine re-operation for a variety of clinical conditions such as psoas tendonitis, periprosthetic fracture and infection. The surgeon noticed that the surface of the heads had a slight loss of polish in some areas and this coincided with a similar mark on the cup. This is the first time that wear stripes of this type have been reported on modern third generation alumina components. The objective of this study was to characterize the wear stripes in terms of their extent and the material failure mechanism that led to their formation. This data will further add to the baseline of knowledge about ceramic articulation for artificial implants and will be essential in validating simulator testing for ceramic-on-ceramic components.

Materials and Methods

Sixteen explanted alumina-alumina couples were analysed in this study. Eleven components had evidence of wear stripes (11 heads and 8 liners). The remaining components, which showed no wear stripes, were used as controls.

Macro examination involved recording dimensional and angular measurements of the stripes and correlating the data with the available clinical information:
On the heads, the length of the stripes and their maximum width, the latitude angle of the centre of the stripe relative to the head equator (‘inclination’ angle,

see figure 1 (a)) and the angle of the long axis of the scar to a line of latitude running through the centre of the scar ('tilt' angle, see figure 1 (b)) were measured.

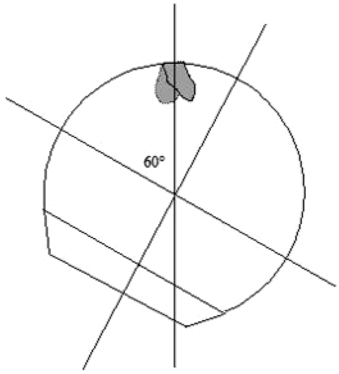

Figure 1a:
Latitude angle of stripe.

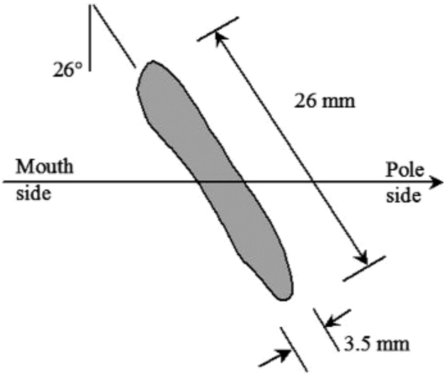

Figure 1b:
Tilt angle of stripe.

On the cups, the circumferential length of the stripes and their maximum width were measured in each case.

For examination at higher magnification, a conventional optical microscope was used. Various lenses were used to image the stripes. For scanning electron microscopy, a number of representative samples were chosen. The heads were mounted on the SEM stub using graphite adhesive, and the area of interest was lightly sputter-coated with gold/palladium to provide conductivity.

Results and Discussion

The following features appeared to be common to all explanted heads and cups showing localised wear stripes:

The worn areas on the heads are usually well defined with sharp boundaries, especially at the ends and on the trunnion side of the stripe, see figure 2(a) and (b). There tended to be more damage outside the main stripe on the pole side than on the trunnion side, see figure 2(b).

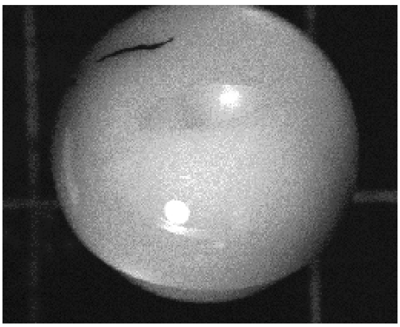

Figure 2a:
Macrograph of stripe on alumina head.

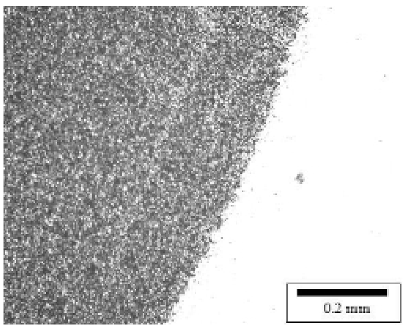

Figure 2b:
Micrograph of well-defined boundary.

The worn areas on the cups were lens-shaped, generally narrower than on the matching head, and were usually located along the 'blend' line between the highly polished hemispherical bearing surface and the less well-polished convexly curved chamfer near the cup edge, see figure 2(c). In a number of cases, it was apparent that a very narrow stripe existed over an extended length of the blend line outside the main lens-shaped stripe, in one or both directions. In extreme cases, the stripe was found to extend beyond this convexly curved region onto the conical chamfer region, along the outer blend line, see figure 2(d).

Figure 2c:
Macrograph of narrow stripe.

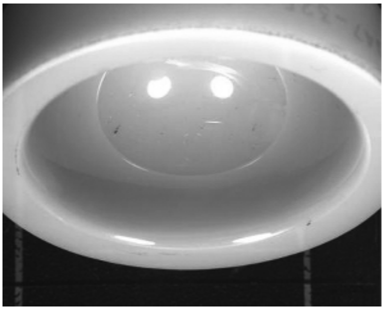

Figure 2d:
Macrograph of narrow stripe.

The lengths of the worn areas on the head and cup are similar, and increase in size with implantation time, suggesting that the initial non-conforming contact of the head on the cup rim becomes conforming with time and/or number of cycles of movement.

Both heads and cups exhibited scratches in the form of lines of pits both within and outside the main stripe areas. Scratches were most prevalent on components with more pronounced stripes. These could be parallel to the length of the stripes, and/or at a steep angle across them. They were often in parallel sets.

There was a wide variation in the tilt angle of the scar to the lines of latitude on the head. Generally, the direction correlated with whether the implant was on the patient's left or right side. All stripes showed a tilt direction that was retroverted, i.e. tilting backwards in respect to the body. There was also a wide variation in inclination angle of the head stripes to the head equator, from 0° to 60°.

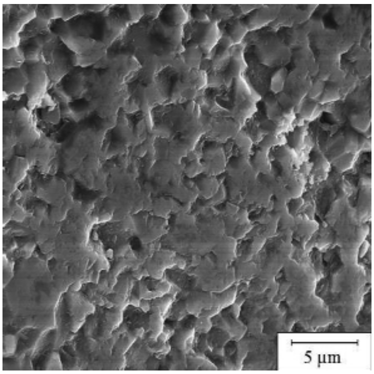

Figure 3:
Head stripe centre region showing grain pull-out.

The SEM analysis of the wear stripes showed that they all comprised of grain pull-out with clear facetted sides to the remaining pits. In some cases, there was evidence of subsequent smoothing over of the surface, almost a partial re-polishing of the surface, with some fine-scale debris being trapped in the pits, see figure 3.

Conclusions

Out of the sixteen explants examined, eleven showed evidence of wear stripes. The components examined with a stripe on the head had a corresponding wear scar on the rim of the cup. The SEM analysis confirms that the initial intense wear process consists of individual grain 'pull-out' followed later by groups of unsupported grains breaking away. Evidence of some repolishing of the pitted surface was also noted at high magnifications. This pitting type of wear, followed by a later smoothing process, is typical of highly localized contacts occurring initially between the head and cup rim over a defined area. As these contacts conform geometrically with increments in the size of the stripe, the wear process becomes less severe and can even lead to partial repolishing of the damaged surface.

In conclusion, the wear scars examined on these explanted alumina-alumina couples were formed through high stress, point contact of the head on the rim of the cup. This, coupled with a lack of lubrication at this point initiated the reported wear stripes without leading to either catastrophic failure or super-critical wear values. This type of contact occurs, in vivo, through microseparation of the head and cup and this mechanism needs to be incorporated into modern simulator testing of alumina-on-alumina components and also other hard-on-hard bearings.

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