THE INFLUENCE OF CARBON ION IMPLANTATION OF ALUMINA FOR USE IN BIOMEDICAL BEARING SURFACES

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INTRODUCTION

The use of ion implantation for biomedical applications has been reported to improve the wear resistance, friction, hardness and wettability of bearing surfaces [1]. This process forms a modified near-surface layer, which has no sharp interface, thus avoiding the adhesion problems experienced with other biomedical coatings.

An interesting development in the field of ion implantation is the use of carbon (C) implantation to aid in the lubrication of surfaces used in bearing and wear environments. Studies into the friction and wear of C implanted alumina have reported a dramatic decrease in the friction, and hence wear, of the modified surfaces [2].

The aim of this study was to examine the microstructural and tribological influence(s) of C implanting alumina for use in bearing applications.

METHODS

Commercially available biomedical grade alumina with a surface roughness (Sa) of <0.02 μm was used in this study.

Ion implantation was performed on the alumina heads using monocharged C ions at an ion dose of 1 x 10^14 C ions/cm² and a beam energy of 75 keV. Samples for transmission electron microscopy (TEM) were prepared using standard focused ion beam thinning techniques and examined in a JEOL 2000FX. A software simulation (TRIM) was used to approximate the distribution and range of the implanted C ions and was correlated with the TEM data. Friction testing was carried out on a Hip Joint Friction Simulator (similar to that used by Unsworth et al. [3]). The loading cycle had a range of 100 to 2000 N, with an amplitude of +/- 25 degrees. Aqueous solutions of carboxymethyl cellulose (CMC) with viscosities of 3.01, 9.22, 37.2, 80.0, 97.2 and 139.0 cP, were used as lubricants. Unimplanted and C implanted alumina heads and an alumina bearing couple after five million cycles in a wear simulator (Leeds University, UK) were used to generate Stribeck plots. The roughness of the ceramic heads was measured using an optical interferometer (WYKO NT2000). Eight measurements were made at the polar, 30° and equatorial regions of the heads and overall averages for Sa, mean deviation of roughness from the measurement plane) and Sdq (root mean square deviation of roughness from the measurement plane) were then calculated for all eight measurements.

RESULTS

The near-surface microstructure of the unimplanted and implanted alumina can be seen in Figures 1(a) and (b). The formation of a subsurface amorphous layer, beneath which, lies a high density of dislocations can be observed in the C implanted alumina (see Figure 1(b)). The use of TRIM yielded a close correlation between the simulated C ion distribution and the position of the amorphous zone, the formation of which is likely to be related to the lattice damage created by the implanted C ions. The maximum intensity for the implanted C was found to lie at a depth of some 140 nm beneath the surface of the alumina, the distribution of ions above and below this position being seen to exhibit a degree of asymmetry with the maximum depth of implantation being approximately 225 nm.

The Stribeck plots for the alumina/alumina bearing couples showed a friction factor that decreased with increasing viscosity indicating mixed-mode lubrication. The friction factor for the C implanted alumina-on-alumina bearing couples decreased by up to 85% for low viscosities (< 9.22 cP) compared to that of unimplanted alumina bearing couples. Wyko results can be seen in table 1.

Table 1

<table>
<thead>
<tr>
<th>Mode</th>
<th>Sa (nm)</th>
<th>Sdq (nm)</th>
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<tbody>
<tr>
<td>Unimplanted head</td>
<td>3.40 +/- 0.42</td>
<td>4.30 +/- 0.53</td>
</tr>
<tr>
<td>C implanted head</td>
<td>1.27 +/- 0.23</td>
<td>1.80 +/- 0.53</td>
</tr>
<tr>
<td>5 million cycle head</td>
<td>1.06 +/- 0.13</td>
<td>1.36 +/- 0.18</td>
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DISCUSSION

At viscosities comparable to that of synovial fluid in a healthy human joint, C implantation of alumina resulted in a reduced friction factor when compared to that of unimplanted alumina (see Figure 2). This decrease can be explained by an increase in the potential for separation of the bearing surfaces due to reduced asperity contact. At the higher viscosities, i.e. > 97.2 cP, the friction factor levels off indicating that a fluid film has formed between the bearing surfaces for all bearing couples.

When a Stribeck analysis was performed on the five million cycle bearing couple, it was found that the friction factor was very similar to that of the C implanted couple. The difference in friction factors for the three bearing couples can be explained by examining the surface roughness data. Surface topography of the unimplanted head indicated a smooth surface containing a degree of waviness resulting in an average Sa value of 3.4 nm (within the parameters as specified by ASTM F-603). Analysis of the roughness of the C implanted head indicated a very smooth surface without the waviness observed in the unimplanted sample. The Sa value of the C implanted sample was found to be 1.27 nm, i.e. a 63% reduction in the surface roughness. This is comparable to the Sa value of the five million cycle head, i.e. 1.06 nm.

Carbon ion implantation of alumina results in ion beam smoothening of the treated surface, hence wear, of the modified surfaces [2]. This process forms a modified near-surface amorphous layer, beneath which, lies a high density of dislocations can be observed in the C implanted alumina bearing couples. When a Stribeck analysis was performed on the five million cycle bearing couple, it was found that the friction factor was very similar to that of the C implanted couple. The difference in friction factors for the three bearing couples can be explained by examining the surface roughness data. Surface topography of the unimplanted head indicated a smooth surface containing a degree of waviness resulting in an average Sa value of 3.4 nm (within the parameters as specified by ASTM F-603). Analysis of the roughness of the C implanted head indicated a very smooth surface without the waviness observed in the unimplanted sample. The Sa value of the C implanted sample was found to be 1.27 nm, i.e. a 63% reduction in the surface roughness. This is comparable to the Sa value of the five million cycle head, i.e. 1.06 nm.

In conclusion, C implantation of alumina was found to modify the near-surface of treated samples. The results from this study also show a beneficial reduction in the average roughness of the treated surfaces, with a corresponding decrease being observed in the friction of treated alumina bearing couples.

REFERENCES


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