ABSTRACT

A novel third generation of Ventricular Assist Devices called Implantable Centrifugal Blood Pump is been developed in order to provide Mechanically Circulatory Support to Congestive Heart Failure patients. The design is based on a conical impeller supported by ceramic pivot bearings in hydraulic levitation between 1400 and 2300 RPM. The proposed friction study consists in checking the mechanical wear occurred during the contact between impeller’s shaft and bearing. This paper presents the superficial characterization of the ceramic pivot bearings after Friction and Wear Tests performed in a workbench that simulates the operation of a centrifugal blood pump with those characteristics. Friction and wear tests were performed with alumina and zirconia ceramic axis in contact with the Ultra-high-molecular-weight Polyethylene (PEUHMW) at a speed of 1800 RPM with 5N load for 10 hours. Lubrication was provided with water and surfaces were analyzed microscopically before and after the induced wear. Results were compared and the superficial damages were checked out with moderate structural modification observed.

Keywords: implantable centrifugal blood pump, alumina ceramic pivot bearings, ventricular assist devices, friction and wear, biotribology.
INTRODUCTION

A third generation of Ventricular Assist Devices (VAD) came up with the use of Centrifugal Pumps in Circulatory Support Mechanical patients with Congestive Heart Failure. Centrifugal pumps before used as cardiopulmonary bypass (CPB) during surgery showed promising advantages. The Bioengineering Laboratory and Biomaterials IFSP is developing a third-generation VAD called Blood Implantable Centrifugal Pump (BSCI) (1). To ensure the reliability of the BSCI, its components should be carefully studied and analyzed (3, 4, 10).

One of these components is the object of study being conducted, the coupling between shaft and bearing that are triggered by the rotor that moves blood flow. The components are: ceramic shaft Alumina (Al2O3) and Zirconia (ZrO2), contact the Polymeric bearing made of Ultra High Molecular Weight Polyethylene (UHMWP) (2).

This research aimed initially chafing of ceramic axes using as component in a test Friction Test bench and Wear (BEAD) located in Biomaterials and Bioengineering Laboratory in IFSPs SP.

MATERIALS AND METHODS

For characterization of ceramic materials and surface analysis of fracture in the samples, we used two microscopes: an axial (Axio lab A1, Carl Zeiss, Oberkochen) and other vertical (Axio Vert A1, Carl Zeiss, Oberkochen) as Figure 1.
For frictional wear tests were made two specimens of each ceramic material: Zirconia and Alumina. The profiles obtained from the axial 100X magnification microscope can viewed in Figures 2 and 3.

**Figure 2** dimensional profile of the shaft 1 and 2, ZrO2 material. original magnification 100X.

**Figure 3** dimensional profile of the shaft 1 and 2, Al2O3 material. original magnification 100X.
The specimens were subjected to tests of approximately 10 hours in BEAD simulating the friction conditions within the BSCI, as Figure 4.

**Proof Body characterization Alumina - Al2O3**

The alumina used in this study was provided by the company INP Biomedical. The specimens were subjected to uniaxial pressing, pre-sintering, green machining, sintering and grinding according to Table 1 specifications.

<table>
<thead>
<tr>
<th>Propriedades</th>
<th>Unidades</th>
<th>Implante Cerâmico de Alumina</th>
<th>ISO 6474</th>
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<tr>
<td>Al2O3</td>
<td>%</td>
<td>&gt; 99.7</td>
<td>&gt; 99.5</td>
</tr>
<tr>
<td>SiO + Na2O (Outros Oxídeos)</td>
<td>%</td>
<td>&lt; 0.02</td>
<td>&lt; 0.1</td>
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<tr>
<td>Densidade</td>
<td>g/cm³</td>
<td>≥ 3.97</td>
<td>≥ 3.94</td>
</tr>
<tr>
<td>Porosidade</td>
<td>%</td>
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<td>-</td>
</tr>
<tr>
<td>Tamanho médio do grão</td>
<td>(µm)</td>
<td>3.6</td>
<td>≤ 4.5</td>
</tr>
<tr>
<td>Resistência à flexão (Mpa)</td>
<td>Mpa</td>
<td>&gt; 500</td>
<td>&gt; 450</td>
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<tr>
<td>Resistência à compressão (Mpa)</td>
<td>Mpa</td>
<td>1100</td>
<td>-</td>
</tr>
<tr>
<td>Acabamento superficial Ra</td>
<td>(µm)</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>Módulo de elasticidade</td>
<td>GPa</td>
<td>360</td>
<td>-</td>
</tr>
<tr>
<td>Tenacidade à fratura Kc</td>
<td>Mpa · m²/</td>
<td>4-6</td>
<td>-</td>
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<tr>
<td>Coeficiente de expansão térmica</td>
<td>x 10⁶/°C</td>
<td>8</td>
<td>-</td>
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<tr>
<td>Conductividade térmica</td>
<td>W/m·K</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>Dureza</td>
<td>GPa</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>Temperatura de Sinterização</td>
<td>°C</td>
<td>1400 - 1600</td>
<td>-</td>
</tr>
</tbody>
</table>
The zirconia used in this study was provided by the company Macéa Technical Ceramics. The specimens were subjected to uniaxial pressing, pre-sintering, green machining and sintering as Table 2 specifications.

### RESULTS AND DISCUSSION

**Axis Alumina**

To check the crystal structure before the initial tests, the upright microscope was used, which enabled the approach 1000X and registration of its structure before the test bench, as Figure 5.
After the tests performed in both axes, microscopy was performed to the nearest 1000X, as Figure 6.

**Axis Zirconia**

For check of the crystalline structure before the test bench was used upright microscope which allowed the approach of 1000X and registration structure before testing bench, as shown in Figure 7. After the tests in BEAD, microscopy was performed to the nearest 1000X, as figure 8.
Figure 7. Micrographs of the surface of the shaft end 1 of the ZrO2 material different radius points / corners. Original magnification of 1000X.

Figure 8. Micrographs after the test of the tip surface of the shaft 1 from the ZrO2 material different radius points / corners. Original magnification of 1000X.

Axis 2 Zirconia presented the following images in vertical with microscopic increase of 1000X, figure 9.

Figure 9. Micrographs of the surface of the shaft end 2 ZrO2 material different distance points / angles. Original magnification of 1000X.
After the trials in ADB, the axis 2 showed images on upright microscope with increased 1000X, as Figure 10.

**Figure 10.** Micrographs after testing the shaft end surface 2 of the ZrO2 material different points radius / angles. original magnification of 1000X.

**CONCLUSIONS**

At observed, there is no dimensional change or any visible wear on 100x magnitude in all axes in the bench tests were performed. This indicates that the erosion of the ceramic material is virtually unnoticeable from the viewpoint of the durability of the BSCI rotor shaft.

During the microscopy performed, however, it was observed some changes on the surfaces of the axes after the tests conducted in BEAD. Some bold dots are visible at 1000x magnification in the shaft 2, on alumina, as can be seen in Figure 6. These points may indicate inclusion of the polymeric bearing material PEUAMM matter, but it was not possible in this study accurately define the origin this inclusion. Another aspect observed in the axis Zirconia, was the presence of areas with no existing gloss before testing in BEAD, as can be seen in Figures 8 and 10. One hypothesis was recrystallization in place due to contact with the ceramic shaft bearing polymer.

The fluid applied to the BEAD during tests that simulate the friction of BSCI was pure water to avoid contamination of samples. The ideal would be to perform assays with blood by controlling parameters such as hematocrit, coagulation, temperature
and hemolysis. Alternatively, to simulate blood viscosity would be to use an aqueous solution containing 37% glycerol. In this study, the ceramic interface display is prioritized with the polymer without any inclusion generated by deterioration of external material. Therefore, in future work is needed to carry out further tests using the mixture of water and glycerine to check the surface and dimensional changes in tribological conditions closer to the real phenomenon.

With the development of new prototypes of BSCI, new tests should be conducted on site to assess the actual wear during operation of the device with the same microscopic evaluation described herein. It is expected that, so it is possible to get a better view of the inclusion of polymeric material phenomena ceramics, changes in its surface, permanent deformation and evaluation of functional parameters of the tribological study of the proposed ceramic material.

REFERENCES


