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Microstructure and tribology regarding precision studies of micro-sintered ceramic bearings for Ventricular Assist Devices

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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 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 bearings. 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 at speed of 1800 RPM with 5.0N load during 10 hours. Lubrication was provided with water and surfaces were analysed microscopically before and after the induced wear. Results were compared and the superficial damages were checked out. The structural modification observed was considered moderate.

Implantable centrifugal blood pump, alumina ceramic pivot bearings, ventricular assist devices, friction and wear, biotribology.

1. Introduction

A third generation of Ventricular Assist Devices (VAD) came up with the use of Implantable Centrifugal Blood Pump (ICBP) [1] in Mechanical Circulatory Support of patients with Congestive Heart Failure. Centrifugal pumps were before used as cardiopulmonary bypass (CPB) during surgery but now they are showing promising advantages as VAD. To ensure the reliability of ICBP, each one of its components must be carefully studied and analysed [2], [3], and [4], since a failure could bring serious consequences to patients.

One component prone to failure are the micro sliding contact bearings used to support the pump rotors. These micro bearings consist of ceramic hemispheric end shaft supported by polymer bearing, Figure 1.

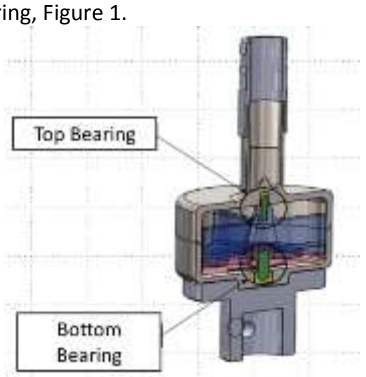


Figure 1. Ventricular Assist Device (VAD), micro sliding contact bearings configuration.

2. Micro Bearings Design

The objective of this research is to study the feasibility of using the ultra-high molecular weight polyethylene / ceramic shaft pair as a pivotal component in ICBP. Tribology-related aspects such as dimensions, profile and roughness were considered in the wear and friction tests performed.

3. Materials and methods

The tribological study performed was based on factors related to the contact of the materials pair in relative movement. Other factors are physical and mechanical properties, the stresses caused by contact and conditions that influence the mechanisms and wear rates of the materials related to the bodies in mechanical contact [4].

The micro sliding contact bearings consist of a ceramic hemispheric end shaft supported by a polymer bearing. Two types ceramic shaft were tested, one in Alumina (Al_2O_3) and the other in Zirconia (ZrO_2). The support bearing consists in a Polymeric bearing made of Ultra-High Molecular Weight Polyethylene (UHMWP) [5].

The tests were performed using the Wear and Friction Work Bench (WFWB) [6]. The specimens were subjected to approximately 10 hours testing, simulating the friction conditions of ICBP, Figure2.

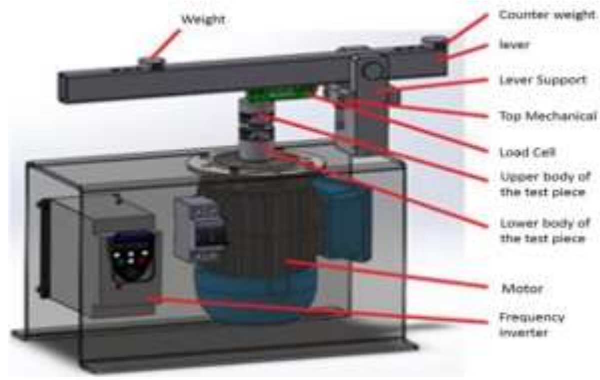


Figure 2. Wear and Friction Work Bench (WFWB).

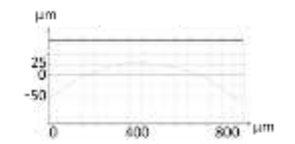
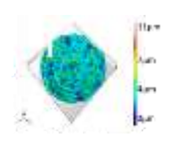
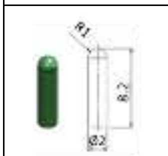
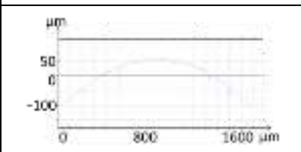
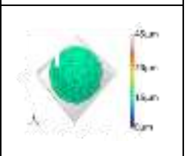
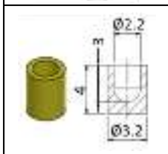
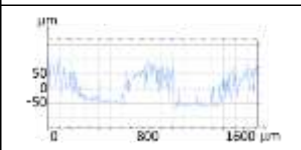
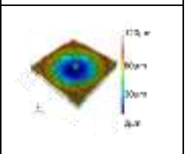
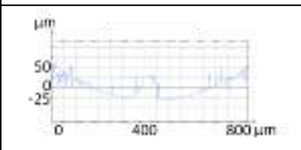
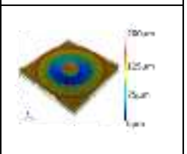
There were carried out testing of ceramic materials shaft / bearings to characterize the abrasion through the VAD, as Figure 1.

The experiments were performed with fluids that have resemblance to blood viscosity [7]. For frictional wear tests, two specimens of each ceramic material were prepared: Zirconia and Alumina [8], [9] and [10].

4. Results and discussion

Table 1 shows the design characteristics of top and bottom micro bearings, ceramic axes and the polymer bearings, with the characterization results of average profile and roughness.

Table 1. Design characteristic of the micro sliding bearings and its characterization.

Dimensions	Average profile	Roughness
		
		
		
		

In order to check the roughness of the specimens before the performance tests in Workbench, a profilometer (CCI MP, Taylor Hobson, Leicester, England) was used to record the surface structure, as seen on Table 1 and Figure 3.

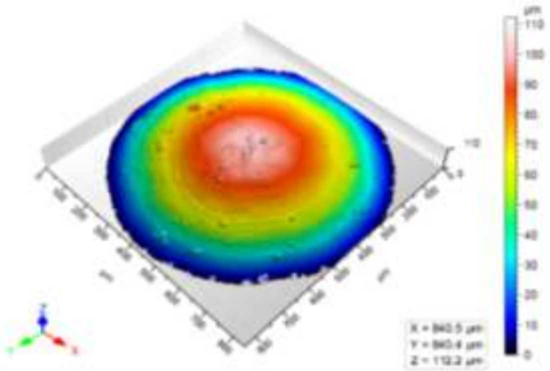


Figure 3. Tridimensional view from the level of removal and filling points unmeasured Axis Z of ZrO2.

In Axis Z, it was detected a higher roughness through graphic 1 horizontal profile with an approximate value of 0.02 mm.

5. Conclusions

As observed, there was no dimensional change or any visible wear on 100x magnitude in all axes in the performed Workbench tests. This indicates that the ceramic material erosion is virtually unnoticeable from the viewpoint of the durability in ICBP's rotor shaft.

During the microscopy performed, however, it was observed some changes on the surfaces of the axes after tests conducted in BEAD. Some black spots were visible at 1000x magnification in the shaft 2, on alumina. These points may indicate inclusion of the polymeric bearing material (PEUAMM) but it was not possible in this study to accurately define the origin of this inclusion.

Another aspect observed in the axis Zirconia, was the presence of areas with no existing gloss before testing in BEAD. One hypothesis was recrystallization in place due to contact between ceramic shaft and polymeric bearings.

The fluid applied during BEAD tests to simulate ICBP friction was pure water to avoid contamination of samples. One option would be to perform assays with blood, controlling parameters such as hematocrit, coagulation, temperature and hemolysis.

An alternative to simulate blood viscosity would be to use an aqueous solution containing 37% of glycerol. In this study, the ceramic interface display was prioritized with the polymer without any inclusion generated by deterioration of external material.

Therefore, further tests using the mixture of water and glycerine to check the surface and dimensional changes in tribological conditions closer to the real phenomenon will be placed in future works.

After several roughness testing in profilometer, shafts and bearings pairs were selected for testing in VAD prototype.

With the development of new ICBP prototypes, new tests should be conducted *"in loco"* to assess the actual wear during device operation with same characteristics described herein.

It is expected that in future works 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.

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