Fretting-corrosion of 316L SS: the role of albumin on the corrosive wear

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Statement of Purpose:

Fretting-corrosion, friction under small displacements, accounts for degradations of materials constituting hip prosthesis and aseptic loosening [1]. Understanding, predicting and improving wear are significant challenges for orthopaedic surgeons and implants industries due to health and society issues. This work aims at studying fretting-corrosion of the contact AISI 316L-PMMA for simulating the 316L-bone contact according to the mechanical properties. For understanding the role of the proteins on the current density, all presented investigations were carried out at applied potential, close to the open circuit potential. The effect of chloride ions (ionic strength) is highlighted on the wear rate of the stainless steel submitted to fretting-corrosion. Moreover the proteins effect, in model solution, shows a corrosive protecting effect of the 316L wear by fretting-corrosion. The mechanical wear is promoted by albumin.

Methods:

The 316L sample is: 9 mm x 9 mm x 20 mm parallelepiped. One of the flat parts (9 mm x 20 mm) was polished with diamond paste down to 1 µm. This pristine friction surface exhibits a 3D roughness, Sa, about 10 ± 2 nm (VeecoTM optic profilometer).

The PMMA sample is cylindrical. The 3D roughness, Sa, is about 35 ± 5 nm.

Two solutions are investigated: Ringer solution (for reproducing the physiological liquid) and NaCl solutions, with concentrations of 10^{-3}, 10^{-2}, 10^{-1} and 1 mol.L^{-1}.

Room temperature was of 22 ± 1 °C. To understand influence of proteins on fretting behavior, 1 g.L^{-1} of albumin was added in each saline solution.

For reproducing the fretting-corrosion degradations, a specific device was used; it was developed by ENSM-SE and Böse. The obtained results were compared with previous investigations and they are in accordance with [2]. The test duration of fretting is about 14400 seconds (1 cycle is 1 second) for each test.

Electrochemical investigations were managed thanks to the PARSTAT 2263 potentiostat with a three-electrode set up. The applied potential was of -400 mV vs. SCE (Standard Calomel Electrode), close to the free corrosion potential. Thus the current density was monitored.

Wear volumes of PMMA and 316L SS are obtained thanks to Veeco^{TM} WYKO NT9100 optical profilometer. The electrochemical measurements allow getting current density and the profilometry is the mean for calculating the total wear volume. Thus the contribution of mechanics and corrosion is investigated.

Results:

First of all the free corrosion potential was investigated [3], it represents the actual potential of this metal in the human body. These results were commented in [3].

The first insight of these investigations is the measurement of the current density under fretting-corrosion. From the current density, the corrosive wear volume, from the Faraday law, is calculated. The goal is to highlight the influence of proteins on the corrosive wear compared to the total wear volume.

The Figure 1 shows the evolution of the dissipated energy (area of the curve tangential load vs. displacement) per cycle during fretting-corrosion experiments; the total wear volume and the percentage of the corrosive wear compared to the total wear volume.

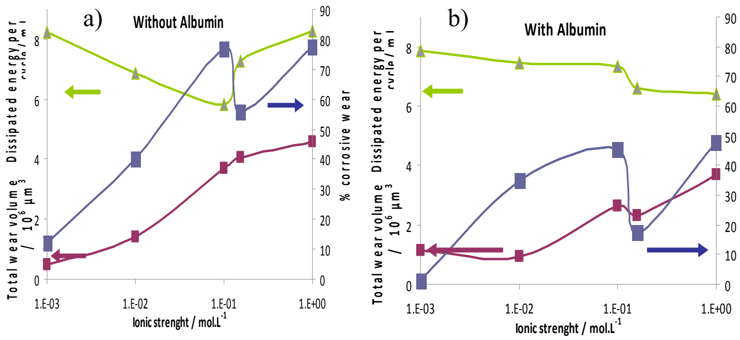

Figure 1. Dissipated energy per cycle / mJ; Total wear volume / 10^6 µm^3; % corrosive wear according to the ionic strength / mol.L^{-1}; Ringer and NaCl solutions; a) without albumin, b) with albumin, 1 g.L^{-1}.

First of all, the ionic strength of 0.1 mol.L^{-1} is a threshold, about the evolution of the dissipated energy and the one of corrosive wear. The wear regime is clearly different at a ionic strength of 0.1 mol.L^{-1}. One may suggest, beyond this ionic strength, degradations are principally involved by corrosion processes. The threshold about the percentage of the corrosive wear is highlighted for the multiple composition of the Ringer solution (NaCl, $CaCl_2$, $NaHCO_3$, etc.). The role of chlorides is essential about the fretting-corrosion behaviour. The salts play a minor role on the dissipated energy (it means mechanically) but a significant role on the corrosive wear volume under fretting-corrosion degradations. Finally, for ionic strength higher than 0.1 mol.L^{-1}, albumin does not promote the corrosive wear, i.e. it promotes the mechanical wear. One might suggest the albumin should not drastically play the role of lubricant but another one about the processes of corrosion.

Conclusions:

0.1 mol.L^{-1} is a threshold concentration; beyond this one, the corrosive wear is promoted. Albumin, a kind of human proteins, plays a major role on the fretting-corrosion degradations of 316L SS, it promotes a mechanical effect. This behavior is particular for the fretting-corrosion compared to friction corrosion. Additional investigations are in progress about the role of the albumin concentration on fretting-corrosion.

References:

[1] Waterhouse R.B., ASTM Special Technical Publication 780, Philadelphia, 1982, 3-16.
[2] Geringer J et al. Wear 2005;259: 943-951.
[3] Pellier J. et al. Wear 2011 under review,