SEVERE CORROSION AND HYDROGEN EMBRITTLMENT OF RETRIEVED MODULAR BODY TITANIUM ALLOY HIP-IMPLANTS

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Statement of Purpose: Titanium alloys have been used in orthopedic applications due a combination of outstanding mechanical properties, biocompatibility and corrosion resistance. Although titanium is considerably resistant to corrosion attack, titanium alloys are known to be susceptible to hydrogen due its high affinity for hydrogen in different environments [1]. Hydrogen interaction with different titanium alloys, leading to the precipitation of hydrides, has been a topic of concern in biomedical applications [2-5]**.** This study will present evidence of severe corrosion attack and hydrogen embrittlement of the surface of Ti-6Al-4V alloy modular stem hip implants *in-vivo.*

Methods: Two samples from a larger study of Ti modular corrosion [6] were chosen for analysis. Both implants, hypothetically named A and B, consisted of modular connections in the stem region where the interface sides consisted of Ti-6Al-4V. Both designs studied are typically used in revision implant surgery. These devices were chosen for analysis because of the severity of the corrosion present. Both the male and female portions were analyzed. The B component was retrieved after a period of 22 months of the implantation and the exact period of the A retrieval is unknown. The cause of revision was infection-related in both cases. Samples were cleaned in various stages from least to most vigorous (the latter being ethanol and water with light abrasion and ultrasonic cleaning). SEM was used to study the morphology of specific corrosion events and to identify brittle regions. The formation of hydrides on the surface was examined by XRD analysis with Cu Kα radiation of wavelength $\lambda = 1.54056$ A in the 2θ angle range from 10^{o} to 70^{o}. Chemical analysis of corroded samples applying combustion technique was performed in a commercial laboratory (Quantitive Technologies, Inc., with a detection limit of 0.10 wt. %).

Results/Discussion: Several features beyond the typical evidence of fretting corrosion have been demonstrated in the SEM analysis. In particular, severe pitting of the surface with pits up to 250 μm and surface cracking in multiple directions were observed (Figure 1). Assigned peaks for the gamma titanium hydride (γ-TiH at $2\theta = 39.5^{o}$, b peak in Figure 2) were observed for the A component and these results were supported by chemical analysis, which indicated hydrogen concentrations in the range of 0.14 to 0.21 wt. %. These results showed hydrogen concentration more than ten times the concentrations recommended by the ASTM standards for titanium alloys. The B component presented qualitative evidence of hydrogen-induced cracking with multidirectional cracking patterns; however the hydrogen levels in these samples were below the reporting limit of the chemical analysis technique (0.1 wt.%) and hydride peaks were not clearly observed with the XRD analysis. Figure 2 shows an example of diffraction pattern for the A component. Crevice corrosion associated with abrasion of the oxide film may create the ideal conditions (low pH, cathodic potentials) for hydrogen to diffuse into the surface of orthopedic implants leading to the brittle cracking and pitting observed in this study.

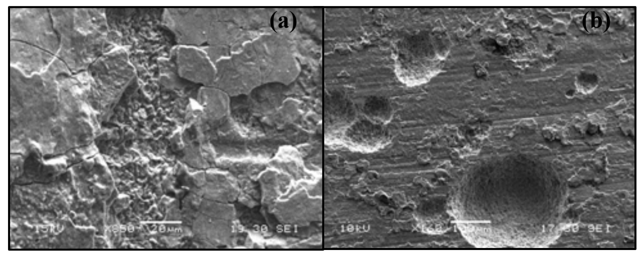

Figure 1. (a) A component showing cracking and delamination (b) Pitting on the B component.

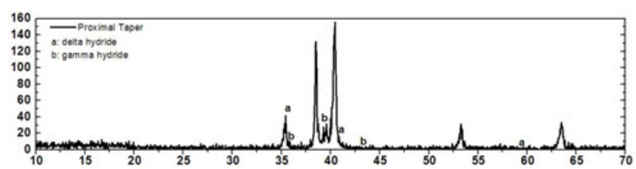

Figure 2. XRD pattern for the A component (female proximal taper).

Conclusions: Ti-6Al-4V/Ti-6Al-4V retrieved modular body tapers were shown to have severely corroded taper interfaces which led to pitting, etching, multidirectional surface cracking and delamination based on SEM analysis. The cracking and delamination morphologies in combination with chemical analysis and XRD analysis demonstrated hydrogen embrittlement in the surface layer of one of the two modular components analyzed. The hydrogen generation and absorption are thought to be a consequence of reduction of hydrogen ions present in the taper crevice from the fretting corrosion process.

References

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