Bond Quality and Corrosion Properties of Titanium Foam on Cobalt Chrome Substrates

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Statement of Purpose:
We have previously reported on the properties of an open-cell titanium foam used on titanium alloy orthopedic implants as a bone ingrowth surface[1]. Limitations exist in applying titanium foam to substrates of complex geometry as well as substrate materials such as CoCr ASTM-F75. In this study, tests were conducted showing the effect of forming and bonding titanium foam to CoCr substrates on coating shear strength, substrate fatigue, corrosion behavior and tensile bond strength.

Methods: Reticulated titanium foam (BIOFOAM®, Wright Medical Technology, Arlington, TN) with an average porosity of 65% was applied to cast F75 substrates by a diffusion bonding process. Sintered CoCr bead coatings were used for controls. Four-point bend testing was conducted per ASTM D790 in order to evaluate fatigue strength of titanium foam coated CoCr substrates. Corrosion testing was conducted by immersing titanium foam coated and porous bead coated 58mm acetebular shells in 150ml phosphate buffered saline solution at 37°C for a time period of 6 weeks. Metal ion levels within the solutions were measured using inductively coupled plasma mass spectrometry. Shear fatigue strength of titanium foam coating on CoCr substrates was tested per ASTM F1160. The tensile bond strength of titanium foam after diffusion bonding to an acetabular shell was tested by wire EDM cutting 10mm diameter cylinders out of the coated shell and performing a tensile test according to ASTM F1147.

Results: The titanium foam coating achieved run-out (10,000,000 cycles) at a shear stress of up to 12.3MPa. An F/N curve comparison to existing Titanium porous bead coatings on Ti6Al4V substrates showed that the fatigue life of the bond between the titanium foam and CoCr substrate was greater – with porous bead coatings reaching only 74,000 cycles at a shear stress of 8 MPa.

The corrosion test showed that after 6 weeks, ion concentrations of Co and Cr in the 150ml phosphate buffered saline solution samples were lower for the titanium foam bonded to CoCr shells than for comparative CoCr porous bead coated shells. As shown in Figure 1, the Cr ion concentration was measured to be 0.6ppb for the titanium foam coated shells, while it was 6.6ppb for the porous bead coated shells. The Co concentration was 39.2ppb for the titanium foam coated shells, while it was 289.2ppb for the porous bead coated shells. A negative control sample, taken from solution with no parts immersed, showed <1ppb of both Co and Cr ions.

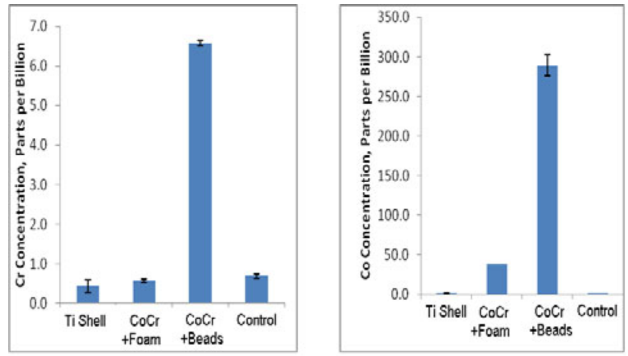

Figure 1. Cr and Co concentration measured in solution after corrosion test.

Tensile testing of the bond between titanium foam and the CoCr shells did not yield bond failure, but failure of the fixturing tape used in the test at an average stress of 63MPa.
An F/N curve comparison between substrate fatigue-life of titanium foam parts vs. the CoCr bead parts showed favorable results for the titanium foam, with a run-out load twice that of porous bead coated parts. This can be explained by the lower heat treating temperature used in the diffusion bonding process, when compared to the sintering process used in porous bead coatings, and the resulting higher hardness of the substrate material.
Conclusions: A method was developed to successfully form titanium foam and bond it to CoCr orthopedic implant substrates. The bonding process did not adversely affect the fatigue strength of the substrate material, and the bond strength in both static and fatigue testing exceeded that of sintered bead coatings. The use of a titanium foam coating resulted in 86% and 91% reductions in the amount of cobalt and chromium ions, respectively, released in vitro from a cobalt chrome acetabular shell.
Being able to form and bond titanium foam successfully to CoCr substrates significantly increases its range of possible applications in orthopedics. In addition, the reduction of metal ion levels in vitro compared to porous bead coated parts is of interest in light of concerns regarding adverse tissue reactions as a result of Co and Cr ion release.

References: 1) “Highly porous titanium foam for orthopedic implant applications” *D. Scholvin, R. Obert, M. Carroll, R. Urban, T. Turner, D. Hall, J. Moseley (USA)* Metfoam Conference 2009, Bratislva, Slovakia