Shear, Tensile and Fatigue Properties of a Titanium Foam Coating on Ti6Al4V Substrates

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Statement of Purpose: In recent years, interest has grown to replace conventional porous coatings on orthopeadic implant surfaces with highly porous materials such as metal foams. One of the challenges is to create a strong bond between the coating and the substrate materials without causing the substrate properties to deteriorate. In this study, bond strength and substrate fatigue were evaluated for a novel titanium foam coating.

Methods: Metal foam sheets manufactured from commercially pure titanium by Wright Medical Technology (WMT) were bonded to Ti-6Al-4V substrates. The titanium foam used for these tests had 65, 70 and 75% porosity, as determined by measured density. Lap shear testing was conducted per ASTM F-1044 (6 parts for each porosity), tensile pull-off testing was conducted per ASTM F-1147 (5 parts for 65%, 4 parts for 70 & 75%). The strain rate was 0.04167 mm / sec.

A four point bending fatigue test was used to evaluate the coating's effect on the substrate. Substrates were machined to 4 x 0.5 x 0.25 inches from Ti-6Al-4V bar stock. The first group of 10 bars was coated with a 75% porous, 2 x 0.5 x 0.060 inches thick titanium foam sheet (see Figure 1). The second group of 10 bars was coated with a 2 x 0.5 x 0.060 inches porous bead layer. The porous bead layer was identical to the porous bead coating used on tibial bases manufactured by WMT. The third group of 10 bars was left uncoated, but underwent the same thermal treatment as the coated parts. Parts were tested in a four point bend fixture with a top span of 30mm and a bottom span at 60mm. The test was load controlled and conducted at a frequency of 15Hz.

Figure 1. Ti foam coated and uncoated substrates.

Results/Discussion:

Table 1 shows the coating shear and tensile pull-off strengths for all groups. Differences in bond strength between coating and substrate could not be observed. The failure at the reported shear and tensile stresses occurred not within the parts, but rather within the adhesive tape used in the test, as shown in Figure 2. Since the titanium foam exceeded the tape strength, the actual interfacial strength must be greater than the values reported in Table 1. Hence, comparisons between the different percent porosities could not be drawn. The FDA guidance for modified metallic surfaces requires a minimum of 20 MPa for both shear and tensile strength of the coating. All of the tested components substantially exceeded this requirement.

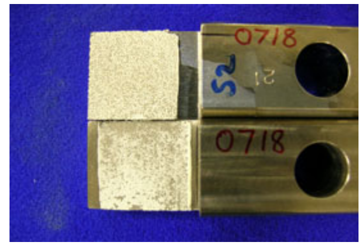

Figure 2. Tape failure of Ti foam lap shear samples

Table 1. Shear and tensile strength of titanium foam coatings.

Table 1. Shear and tensile strength for 65, 70 and 75% porosity titanium foam.

Bulk Material ID	Porosity	Shear Strength, Mpa	Standard Deviation, Mpa	Tensile Strength, Mpa	Standard Deviation, Mpa
Ti0201-02	65.0%	41.4 (n=6)	2.6	43.4 (n=5)	16.6
Ti0817-01	70%	38.6 (n=6)	1.6	56.2 (n=4)	1.3
Ti0307-01	75.0%	40.3 (n=6)	2.5	52.3 (n=4)	9.4

Figure 2 shows an S/N curve of the data collected in the substrate fatigue test. Logarithmic trendlines were fitted to each of the three data sets. While a decline in cycles to failure was observed between coated and uncoated samples, no significant difference between porous bead and foam coated samples was observed. Run-out (10,000,000) cycles was reached by each group, at 176 MPa for the porous bead coated parts, 220 MPa for the titanium foam coated parts and 483 MPa for the uncoated substrates.

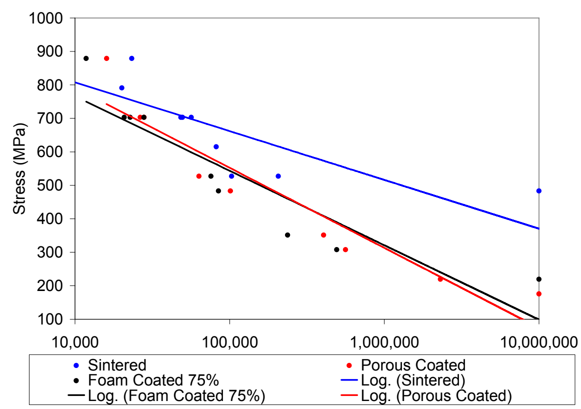

Figure 2. S/N curve for coated and uncoated specimens.

Conclusions: The titanium foam was found to be a suitable coating for orthopedic implants, meeting requirements for both tensile and shear strengths. The tests proved both the interfacial quality as well as the mechanical integrity of the foam structure itself.

It was also shown that although applying a titanium foam coating reduces the fatigue strength of Ti-6Al-4V substrates, it was equivalent to clinically used sintered bead coatings.