Measuring the Adhesion of Ti/HA Coatings to Non-Metallic Implant Materials

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Introduction:

Novel biomaterials may offer alternatives to metal arthroplasty bearings. To employ these materials in thin, bone conserving implants would require direct fixation to bone, using Titanium/HA coatings. Standard tests are used to evaluate the adhesion strength of coatings to metal substrates [1], versus FDA pass criteria [2]. In tensile adhesion testing, a disc is coated and uniform, uniaxial tension is exerted upon the coating-substrate interface; the strength is calculated from the failure load and surface area. Rapid failure occurs when the peak interface stress exceeds the adhesion strength, as local failure will propagate into an increasing tensile stress field.

Ceramics and reinforced polymers (e.g. carbon-fibre-reinforced PEEK), have considerably different stiffness (E) and Poisson's Ratio (ν) from the coating and implant metals. We hypothesised that this substrate-coating stiffness mismatch would produce stress concentrations at the interface edge, well in excess of the uniform stress experienced with coatings on similar stiffness metals.

Methodology:

The interface tensile stress field was predicted for the ASTM F1147 tensile strength test with a finite element analysis model, with a 500µm thick coating (50µm dense Ti layer, 450µm porous Ti/HA/adhesive layer), bonded to a stainless steel headpiece with FM1000 adhesive (Fig.1). Solutions were obtained for:

A. ASTM-standard geometry with Ti-6Al-4V (E=110GPa,ν=0.31), CoCrMo (E=196GPa,ν=0.30), ceramic (E=350GPa,ν=0.22, e.g. BIOLOX delta) and CFR-PEEK (E=15GPa,ν=0.41, e.g. Invibio MOTIS) substrates.

Modified models were used to analyse oversized substrate discs:

B. coated fully and bonded to the standard diameter headpiece, and
C. Coated only where bonded to the headpiece.

Results and Discussion:

Substrate Material	Ti-6Al-4V	CoCrMo	Ceramic	CFR-PEEK	Ceramic	
Test Configuration	A	A	A	A	B	C
Total Diameter /mm	25.4	25.4	25.4	25.4	36.0	36.0
Coated Diameter /mm	25.4	25.4	25.4	25.4	36.0	25.4
FE Peak Stress (Normalised)	1.00	1.16	1.80	3.57	0.99	2.50

The stiffness mismatch between the coating and the ceramic and CFR-PEEK substrates was predicted to introduce, respectively, a 1.80x and 3.57x stress concentration compared to a Ti6Al4V substrate (Fig.2), thereby reducing the failure load for a given interface strength. These predictions consider the test stress distribution only, and do not assess the coating-substrate interface strength. However, the failure load is a function of the interface strength and the peak test stress, so the standard test and stress calculation for stiffness-mismatched substrates may indicate artificially low adhesion strength.

The test may be modified to suit a particular material combination. As an example, for ceramic substrates the results indicate that an oversized, fully coated specimen (B) would experience stress closest to the standard's intended uniform stress field, suggesting that this configuration would be more appropriate. The stress distribution may be sensitive to the coating thickness, so tests should be verified accordingly.

Conclusion:

The ASTM coating tensile adhesion strength test standard was predicted to generate a non-uniform interfacial stress for ceramic and polymer composite substrate materials. The standard may not be directly applicable for non-metal substrates as the stiffness mismatch needs to be considered.

References:

[1] ASTM F1147-05 (2011)

[2] FDA Doc No.946 (2000)

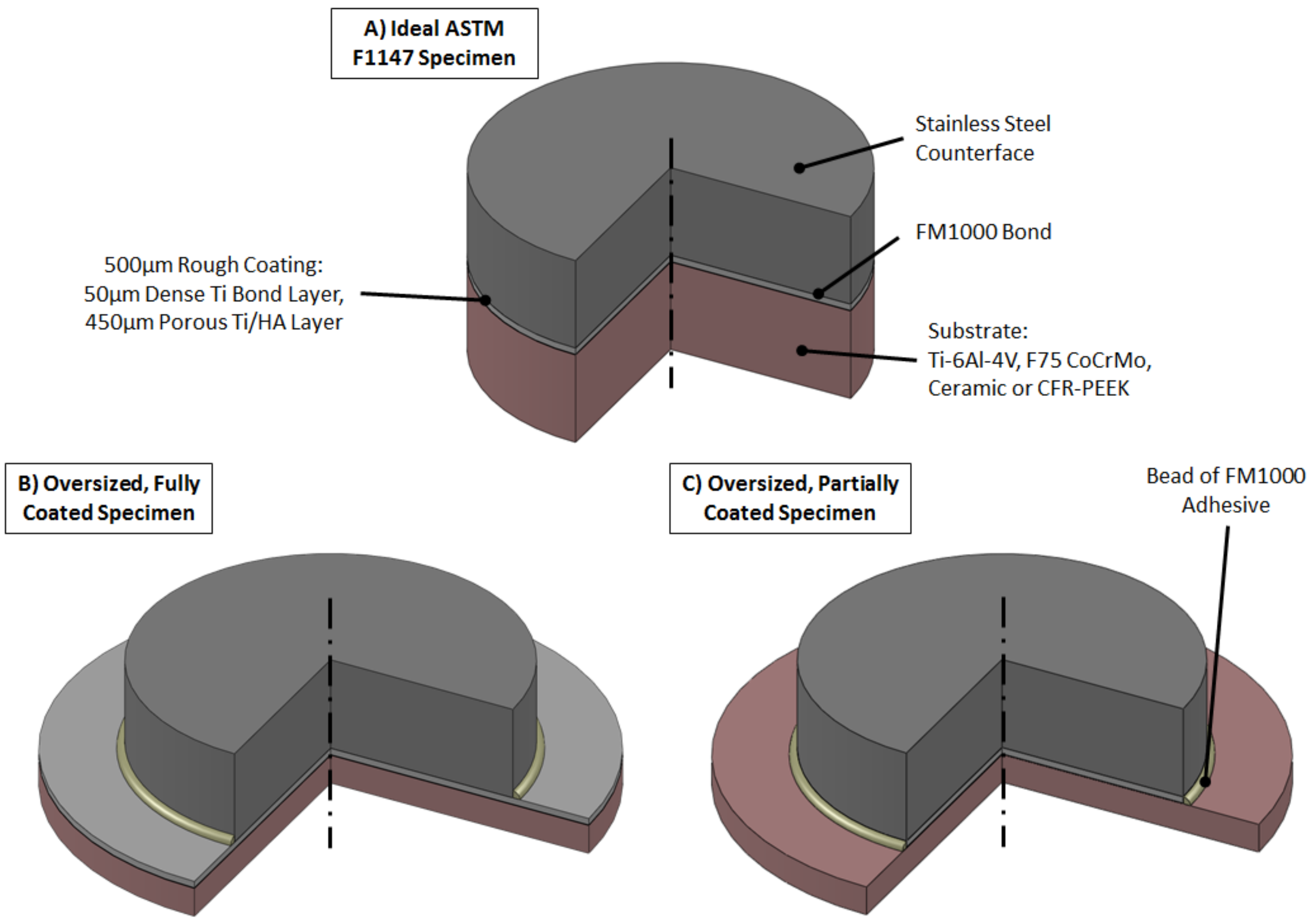

Figure 1: Specimen configurations modelled, as ASTM F1147 (A), and oversized, fully (B) and partially coated (C).

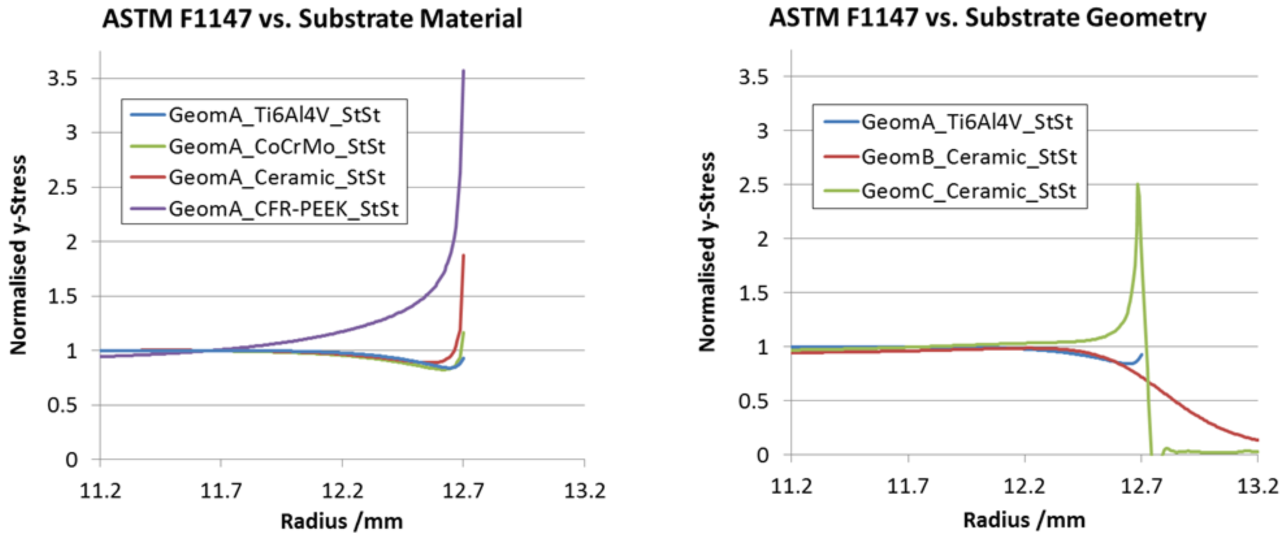

Figure 2: Substrate-coating interface stress distributions comparing ASTM F1147 for different substrate materials (Model A, left), and oversized substrate (Models B and C, right).