The Effects of Fixturing on Porous Coating Strength Testing - A Finite Element Study

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INTRODUCTION: Porous coatings manufactured by spraying, sintering or additive manufacturing represent a critical technological advancement in the field of orthopedics, fundamentally altering the paradigm of implant fixation and long-term performance. These specialized surface modifications are engineered to facilitate osseointegration, thereby promoting a durable biological interface between the implants and host bone. The adhesive strength of a porous coating is a critical determinant of the clinical success and long-term viability of orthopedic implants. ASTM F1147, Standard Test Method for Tension Testing of Calcium Phosphate and Metallic Coatings, specifies a method of testing the adhesive strength by gluing a flat coupon with a porous coating to the same size fixture for an axial pull testing. In practice, an alternative testing method is often used by gluing the often-curved porous surface on the device directly onto the flat fixture. While the alternative method has advantages of generating testing results directly from the more readily available devices, it was not well understood if these two methods are equivalent. In particular, the stress level differences at the coating interface under these two methods has never been investigated. In this study, a Finite Element Method (FEM) was used to investigate the interface stresses. In addition, a new testing fixture design was proposed with a stress field that better reflects the testing intention.

METHODS: As shown in Figure 1, three models (standard, curved and extended) were analyzed in this study. The standard model is to simulate the testing setup in ASTM F1147. The curved model is to mimic a testing setup where the fixture is glued to a cup with a curved porous layer. The extended model is to simulate an alternative ASTM testing setup where the coupon has a larger diameter (25.4mm) than the fixture. All models have identical material assignments for the components. The substrate was made of typical Titanium alloy (E=110 GPa, μ=0.33). The fixture was made of typical stainless steel (E=220 GPa, μ=0.3) and the porous coating was assigned as a soft homogeneous material (E=1GPa, μ=0.23). All models were simplified as axisymmetric models. All models were then meshed using hex elements. The bottom surface of the substrate was fixed, and a uniform pressure (10N) was applied at the top surface of the fixture to simulate the axial pull testing. All components were "tied" together at the interfaces. All models' setups and simulations were conducted using Abaqus software. The model setups and a typical mesh can be seen in Figure 2.

RESULTS: Figure 3 shows the Von-Mises equivalent stress plots at the interface between the porous layer and the substrate for all three models. The X-axis represents the distance (mm) from the center to the edge of the substrate while Y-axis represents the Von-Mises equivalent stress (MPa). While the standard and the curved models have similar stress levels at the center, the stresses at the edge are different. For the standard model, the equivalent stress at the edge rises significantly, causing stress concentration. This is due to the edge effects caused by the mismatch of both modulus and Poisson's ratio. Compared to the standard model, the curved model has minimal stress concentration. The stress is gradually reduced until it reaches zero at its edge. The extended model has a similar stress pattern when compared to the curved model.

DISCUSSION: Our results indicate that the standard and curved testing setups experience different stress levels at the adhesion interface. The standard setup suggested in ASTM F1147 experiences stress concentration due to edge effects. This suggests that these two testing methods may not be equivalent due to different fixturing methods. The standard method has higher stresses and may experience early failure when compared to the curved method. To make an equivalent testing setup to the curved method, an alternative setup using an extended substrate is suggested. This alternative testing setup has a similar stress pattern when compared to the curved method. One of the limitations of this study is that all models in this study are linear. Future studies will simulate nonlinear behavior to better understand the edge effects.

SIGNIFICANCE/CLINICAL RELEVANCE: Per Author's knowledge, this is the first FEA simulation to show the potential differences between a standard testing setup suggested by ASTM F1147 and an alternative testing setup used often in the industry (curved method). This will give the researcher insight into the potential pitfalls when testing the porous coating strength. An alternative testing setup to ASTM F1147 was also proposed to reduce the edge effects.

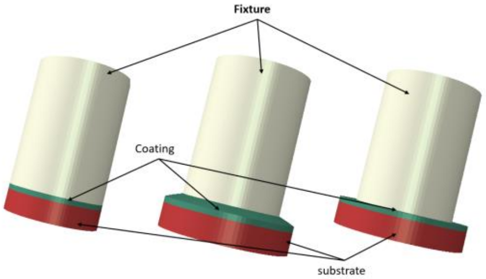

Figure 1, Three Setups (standard, Curved and Extended)

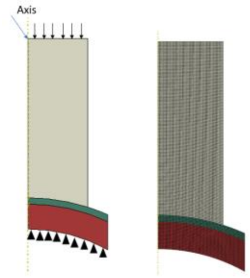

Figure 2, Typical model and mesh (Curved)

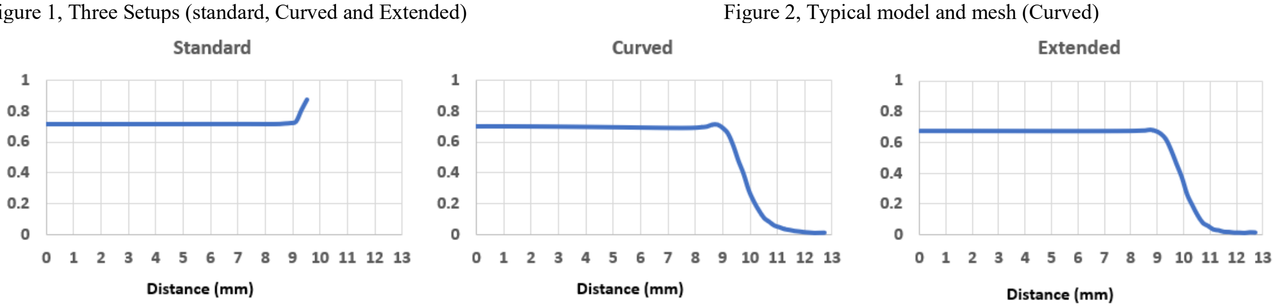

Figure 3, Interface Von-Mises Stress (MPa)