Mechanical Performances of 3D Printed TPMS Scaffolds with High Friction Characteristics

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INTRODUCTION: Recently, 3D printed scaffolds based on Triply Periodic Minimal Surfaces (TPMS) have attracted major interest in the field of regenerative medicine. These 3D printed scaffolds have potential to aid in repair of bone defects due to their trabecular bone-mimicking hyperboloidal topography and customizable mechanical properties. Mathematically, there are many different TPMS configurations, such as Schwarz Primitive (P) and Diamond (D), Schoen Gyroid (G), Schoen I-WP (W), and Neovius (S). We have previously reported that the type of configuration is critical to the friction properties of 3D printed TMPS scaffolds [1]. Our study has shown that among all five configurations compared, type P has the highest static and dynamic coefficients of friction followed by type S, while the most commonly used type G configuration and others have statistically significantly lower static and dynamic coefficients. It is desirable for a bone repair scaffold to have higher friction as it generally leads to better initial stability and eventually better osteointegration. However, the mechanical performance of the scaffold, such as mechanical strength and abrasive resistance, is also critical considering the scaffolds need to carry clinical loads during healing. The goal of this study is to evaluate the mechanical and abrasive performance of two previously identified 3D printed TMPS scaffolds with high friction characteristics (Schwarz Primitive (P) and Neovius (S)).

METHODS: Two previously identified TPMS configurations with high friction characteristics (type P and type S) were included in this study (Figure 1). The porosity (~60%) and unit cell size for all configurations were kept the same to minimize study variables. All specimens were additively manufactured using a Direct Metal Laser Sintering (DMLS) machine (EOS 280) from medical grade titanium alloy (Ti-6Al-4V) based on ASTM F3001, Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion. Three mechanical tests (static tensile, static shear and Taber abrasion) were conducted to characterize the mechanical performance of the specimens. The static tensile test was performed per ASTM F 1147, Standard Test Method for Tension Testing of Calcium Phosphate and Metallic Coatings, and the static shear test per ASTM F1044, Standard Test Method for Shear Testing of Calcium Phosphate Coatings and Metallic Coatings. In these two tests, the cylindrical samples were glued with the fixtures and stressed to failure under either tensile or shear load. The Taber abrasion test was performed per ASTM F1978, Standard Test Method for Measuring Abrasion Resistance of Metallic Thermal Spray Coatings by using the Taber abraser.

RESULTS: A total of 6 specimens were tested for each group and for each test. Figures 2-3 show the results of the static tensile and static shear tests, while Figure 4 shows Taber abrasion test results. It can be seen that both configurations have similar average of the ultimate stress for static shear (53.5 v.s 49 MPa). Although type S configuration has higher average ultimate stress for the static tensile test than type P configuration, the difference is not statistically significant. For the Taber abrasion test, type P configuration shows a statistically significant lower accumulative mass loss after 100 cycles when compared to that of type S.

DISCUSSION: The mechanical performance of two 3D printed titanium TMPS configurations with high frictional behavior have been characterized by this study. The testing results show that both configurations have similar mechanical strength in terms of static tensile and shear loading. When compared to FDA's guidance on porous materials, the mechanical strength of static tensile and shear is well above the suggested value (21 MPa). In addition, the accumulative mass for both configurations is less than 1/3 of the maximum allowable mass value suggested by FDA (65 mg). However, the testing results are limited only to ~60% porosity and certain manufacturing processes. Future studies may be needed to explore more in-depth data for various porosity and different manufacturing processes.

SIGNIFICANCE/CLINICAL RELEVANCE: Per the author's knowledge, this is the first report on the mechanical and abrasive behavior of two TPMS configurations with high friction characteristics. The data provided may be valuable for designing TPMS scaffolds with optimal friction and mechanical behaviors.

REFERENCES: [1] S. Fang, "Friction Properties of 3D Printed TPMS Scaffolds: Are All Configurations Created Equal?", ORS, 2022, Dallas, TX

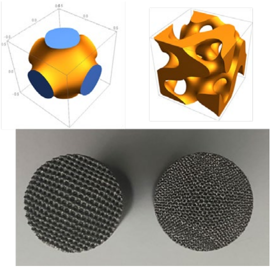

Figure 1: Type S and Type P configurations: Unit cells and Samples

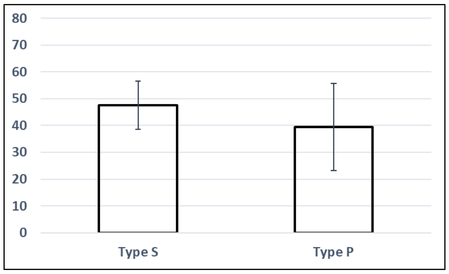

Figure 2: Static Tensile Ultimate Stress (MPa)

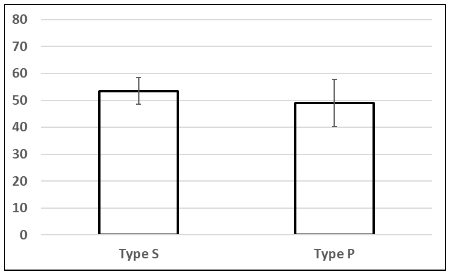

Figure 3: Static Shear Ultimate Stress (MPa)

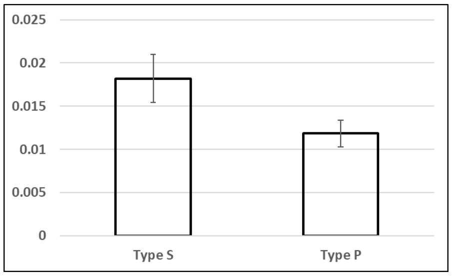

Figure 4: Accumulative Mass Loss After 100 Cycles (g)

ORS 2024 Annual Meeting Paper No. 429