A Microstructual Model to Predict the Mechanical Properties of Porous Tantalum Material

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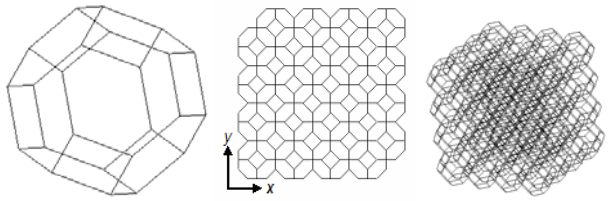
Statement of Purpose: Porous tantalum, known as *Trabecular Metal®,* is a novel biocompatible metallic porous material with great potential for orthopedic applications. Unlike conventional porous metallic coating materials, porous tantalum not only can be used as a coating but also can be designed as a stand-alone structure. For these applications, porous tantalum is designed to provide significant structural support while functioning as a biocompatible scaffold for osseous ingrowth. The performance of these implants such as mechanical strength and biological fixation depend upon the material's porous microstructure and its mechanical properties. Therefore, it is essential to understand the material's mechanical behavior in order to improve future orthopedic implant designs that utilize this material.

As a porous material, porous tantalum's overall mechanical behavior depends on its microstructure. However, the current understanding of this structure-properties functional relationship is limited due to its structural heterogeneity and porous microstructure. From the authors' knowledge, there is no analytical method reported to determine this functional relationship. Consequently, the goal of this study was to develop a theoretical model to investigate the relationship between the material's mechanical behavior and its microstructural geometry by using an analytical method, specifically, the Finite Element Method (FEM).

Methods: The prediction of the material's structure-properties functional relationship was based on the Representative Volume Element (RVE) theory. Two programs, "point3" and "voroni3", were written to generate the material's RVE geometry. These programs are capable of constructing the RVE composed of regular or random Voronoi structures. In this study, the RVE composed of 64 regular three dimensional tetrakaidecahedral cells was used to simulate the material's microstructure (Fig. 1). To compute the material's overall mechanical properties, the RVE was subjected to simple compression. A commercially available FEA software package, ANSYS 10 (Ansys Inc, Canonsburg, PA, USA), was used to analyze the RVE's mechanical behavior. By changing the cross-section area, the relative density of our structure can be adjusted from 5% to about 35% (or the porosity changes from 65% to 95%). For all analyses, the strut material was given isotropic material properties of pure Tantalum as a bilinear elasto-plastic material (Young's modulus E=179 GPa, Poisson's ratio μ=0.34, yield stress σ_y=190 MPa and tangential modulus E_t=17 GPa).

Results: Comparison of the Young's modulus predicted from the current model with the reported experimental results is shown in Figure 2(a). The values were plotted against the material's porosity. It can be seen that value of the Young's modulus of porous tantalum predicted from the current method decreases when the porosity of the material increases, which is a typical mechanical behavior of porous material. Compared with the reported value, the current results agree well.

To compute the material's nonlinear behavior, a large deformation up to 1.6% strain was applied to the model. The overall stress was predicted from the FE analysis. By defining the initial yield stress as the point at which 0.2% offset of strain is reached, the values of the initial yield stress were derived from the overall stress-strain plot and compared with reported experiment data as shown in Figure 2(b). Various values of the material's yield stress have been reported previously. The yield stress reported varies from 4MPa to 50 MPa. Compared with the reported values, the values of yield stress predicted using the current method show a reasonable agreement with reference [2].



(a) A single tetrakaidecahedral cell; (b) Two dimensional view of the RVE; (c) Three dimensional view of the RVE.
Fig. 1: RVE used in the model.

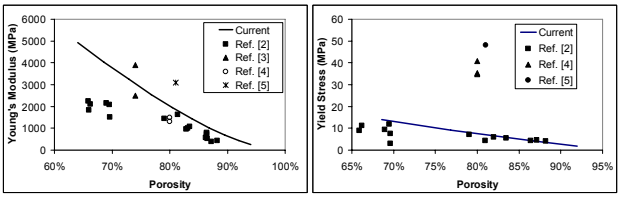


Fig. 2: The predicted linear and nonlinear mechanical behavior. (a)Young's modulus; (b) Yield stress

Conclusions: From the authors' knowledge, it is the first model that is capable of predicting porous tantalum's linear and nonlinear mechanical behaviors. The results show that both the material's linear and nonlinear mechanical behaviors largely depend on the material's microstructure. Compared with the reported experimental values, the current prediction shows a reasonable agreement.

References: [1] Florio *et al.,* (2004) *ORS.* [2] Shimko *et al*., (2005) *j. bio. mat. res.,* 73B. [3] Bobyn *et al.,* (2004) *AAOS.* [4] Zardiackas *et al.,* (2001) *j. bio. mat. res.,* 58. [5] Medlin *et al.*, (2003), *ASM mat. & proc. med. devices*.