Investigating impact of pore size on the mechanical behavior of tissue engineering scaffold: a finite element study

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Abstract

Biodegradable scaffolds are widely used in the tissue engineering in order to provide a temporary structural template for cell seeding and extracellular matrix production. The porosity and pore size are two crucial parameters for scaffold success from both of mechanical and biological views. Although the influence of porosity on the mechanical behavior of scaffold was well-determined, studies about the impact of pore sizes are rare. This study was an attempt to determine the influence of variation in the pore size on the mechanical properties of a scaffold. For this purpose, finite element models with different pore sizes in the range of 40-350 m were constructed in Abaqus software by use of Python scripting considering three different porosities of 55%, 70%, and 85%. Material properties of Poly (D, L-lactide) - PDLLA were assigned for entire models. Results show that by increase in the scaffold pore size, the effective Youngs modulus decreases with power functions. On the contrary, the calculated maximum von Mises stress on the scaffold showed reduction with the second order polynomial functions by increase of pore size with. The increase of the poro size caused about 13% reduction in the effective Youngs modulus, and 12% to 22% increase in the stress. Results of this study can be used to better understanding of internal architecture impact on the mechanical behavior of scaffold.

Introduction

Tissue scaffolds plays an important role in the process of cell attachment, proliferation, and development of tissue formation. In order to function as a true tissue substitutes, tissue scaffolds not only should provide a suitable circumstances for cells activities (biological view) but also meet mechanical requirments. In the mechanical view, the designed scaffold must provide structural support at the site of replacement and to guide tissue regeneration. To address these considerations, the scaffold is often designed as a porous structure with appropriate porosity, pore size, and shape. Research has shown that both mechanical and biological properties of porous scaffolds, as well as cell growth and migration processes are determined in part by the local microarchitecture of scaffold [4, 3, 1].. Overall porosity and specific pore size of the scaffolds should be regarded as crucial parameters that determines both mechanical and biological behavior of the scaffolds. Influence of porosity on the mechanical behavior of the scaffolds has been scope of various studies, and its importance has been well-determined [2, 5]. However, based on our knowledge, there is no study in the literature which investigated influence of pore size on the mechanical properties of the scaffolds; Therfore, the goal of this study was to investigate impact of the variation in the pore size on the mechanical behavior of the tissue scaffolds.

Materials and Methods

Finite element approach was used in this study. Design of the scaffolds was based on the hexagonal prism unit (figure 1). Three porosities of 55%, 70%, and 85% were selected because they are common porosities used in the literature. Modeling and analysis both were implemented in Abaqus (6.11-1) software using custom Python codes which takes two inputs of porosity and pore sizes, and create a model automatically for analysis. The dimension of the models were $2 * 2 * 2mm^3$, and the method of geometry creation were shown graphically in figure 1, in which for considered porosity different models were constructed with the pore sizes in the range of $40 - 350m$. Material properties of Poly (D, L-lactide) - PDLLA were assigned for entire models. Load applied as a displacement on the top of the scaffold, and the bottum was fixed. Tetrahedral element with quadratic shape (C3D10) was used for discritization.

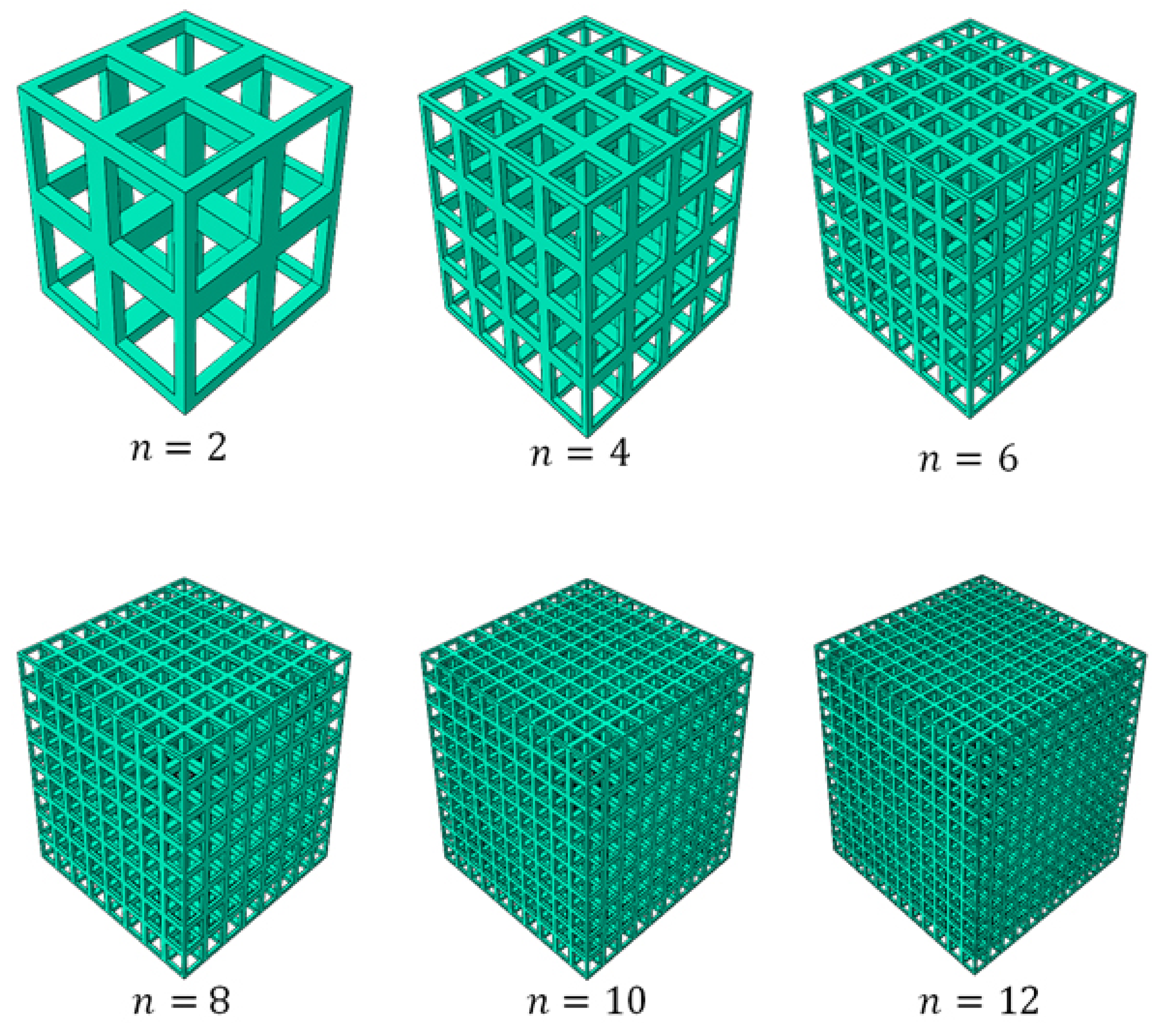

Figure 1: The generated FE models with different pore sizes. For each porosity of 55%, 70%, and 85% , different models with the pore sizes in the range of $40 - 350$ were constructed.

Results

Two factors of effective Young's modulus and von Mises stress were calculated in order to make a comparison between different models. It is shown that by increase in the scaffold pore size, the effective Youngs modulus decreased with spower functions (figure 2). The decrease in the effective Youngs modulus was about 13% for all three porosities. The calculated maximum von Mises stress on the scaffolds showed different senario, in which by increase in the pore size the stresses reduced by second-degree polynomial functions (figure 3). The magnitude of reduction varied with different porosities. For the porosity of 55%, the maximum reduction was 22%, while this magnitude reduced to 12% for the porosity of 85%.

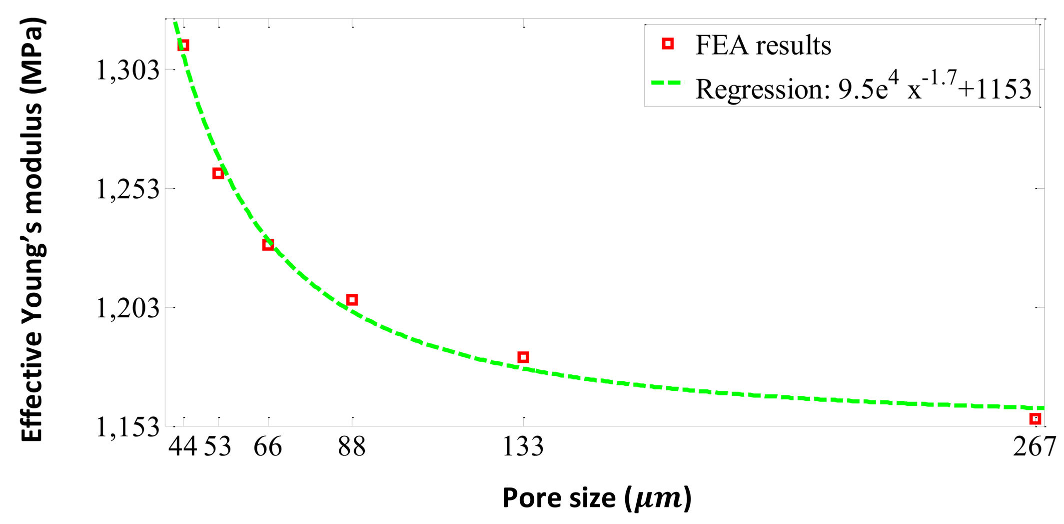

Figure 2: The calculated effective Young's modulus for different pore sizes were imported to Matlab, and a power function fitted to the data.

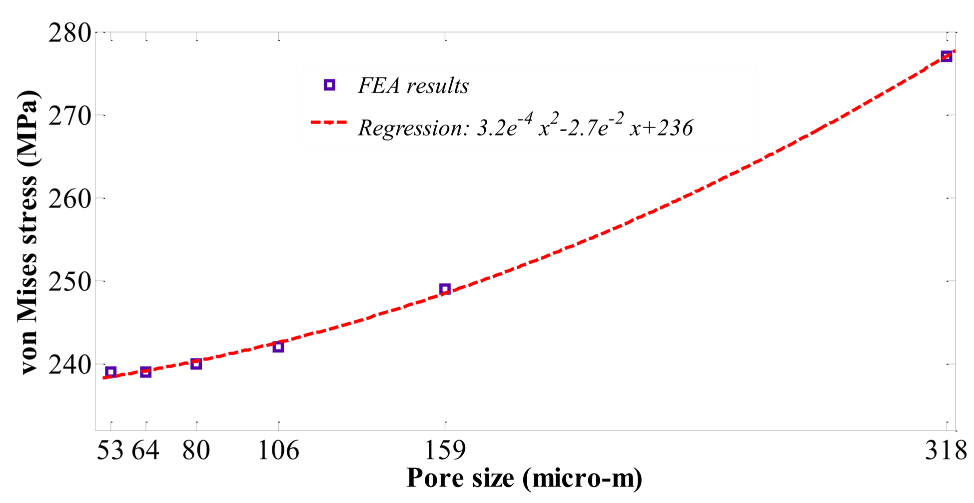

Figure 3: The calculated maximum von Mises stress for different pore sizes were imported to Matlab, and a second order function fitted to the data.

Conclusions

- Change in the pore size plays an important role in the mechanical behavior of the tissue scaffolds.
- Using larger pore sizes brings more flexibility for the scaffold, and consequently causes trasmision of higher mechanical signals into the cells located at the scaffolds.
- Using larger pore sizes, on the other hand, increases the risk of failure.
- Results of this study can be used to better understanding of internal architecture impact on the mechanical behavior of scaffold.

References

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