COMPRESSIVE DEFORMATION MECHANISMS OF POROUS REINFORCED PLLA COMPOSITE STRUCTURES

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Keywords: *Tissue engineering, PLLA, scaffold, reinforcement, mechanical properties, finite element analysis*

1 Introduction

In the tissue engineering field, three-dimensional porous structures have extensively been studied as scaffolds for cell seeding and growth. A regenerated tissue consisting of a scaffold and cell is supposed to be implanted into the damage portion of the target tissue to be reconstructed. Therefore, the regenerated tissue needs to have biomechanical compatibility with the surrounding tissues.

Biodegradable thermoplastic polymer, poly(L-lactide) (PLLA) has widely been used in medical fields mainly due to its bioabsorbability, biocompatibility and mechanical properties. In recent years, PLLA has been considered as one of the promising candidates for scaffold in regenerative medicine. However, the mechanical properties of PLLA scaffolds are not enough to be used for regeneration of hard tissues.

The primary aim of the present study was therefore to improve the mechanical properties of porous PLLA scaffold by introducing reinforcement structures such as solid beam and shell type reinforcements. Compressive mechanical properties such as elastic modulus were evaluated to assess the effects of the reinforcements. A simple linear elastic theory was applied to predict the compressive modulus. The finite element analysis (FEA) was also performed to examine the three-dimensional deformation behavior of the reinforced scaffolds.

2 Experimental

PLLA pellets were used to fabricate scaffolds. The solid-liquid phase separation and freeze-drying methods were applied to construct the porous structures [1]. As the reinforcements, a solid beam with the cross-sectional area of 1x2 mm^2 and a shell of 250μm thickness were fabricated from PLLA by using a thermal-press technique [2].

The compressive mechanical properties were evaluated by conducting compression tests of the scaffolds using a conventional mechanical testing machine at a displacement rate of 1mm/min. The elastic modulus of the scaffolds were estimated from the linear elastic theory by using the following formula:

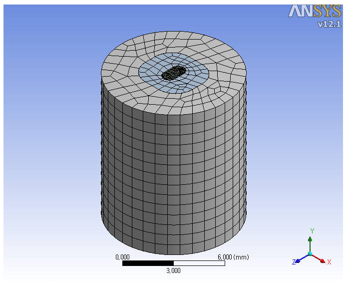
$$E_{Theory} = \frac{1}{A_T}(E_R A_R + E_M A_M + E_B A_B) \qquad (1)$$

where E and A are the modulus and the cross-sectional area of each component. R, M and B correspond to the reinforcement, matrix and boundary layer, respectively.

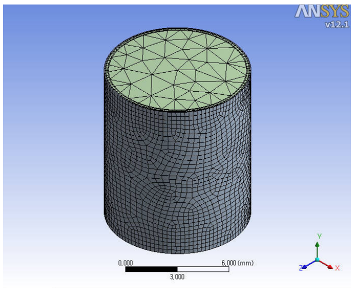
The FEA models of the reinforced scaffolds are shown in Fig.1. For each scaffold, a boundary region was assumed to exist between the reinforcement and the porous matrix. A simple compressive loading condition was introduced as the boundary condition.

3 Results and discussion

FE-SEM micrographs of microstructures are shown in Fig.2. The beam scaffold clearly showed the solid reinforced part and the porous region. The porous region is supposed to be used for cell seeding and growth. The solid part mainly works as the load-bearing component. Thin reinforced shell structure can be observed in the shell scaffold as shown in Fig.2(b). It is also noted that the beam and shell reinforcements were firmly connected to the surrounding porous matrices. The interconnected regions, called boundary regions, had lower porosity with smaller pore sizes than the matrix regions. It is thought that the solid reinforcements were slightly

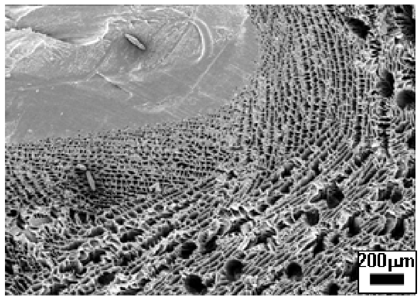


(a) beam scaffold

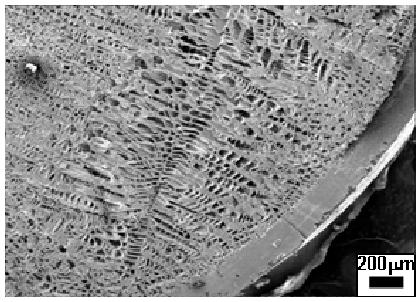


(b) shell scaffold

Fig.1. Computational models



(a) beam scaffold



(b) shell scaffold

Fig.2. Microstructures of reinforced scaffolds

dissolved into the PLLA solution during the fabrication process and therefore, the density of the boundary regions increased.

The results of comparison of the compressive moduli are shown in Fig.3. The beam scaffold showed the largest modulus and the difference between the beam and the shell scaffolds was small. It is thus understood that the beam and the thin shell reinforcements result in the similar strengthening effects on the modulus. It is noted that the moduli of the reinforced scaffolds were about 5-6 times larger than the mono. The results of the theory and FEA were slightly higher than the experimental values. This might be related to the structural conditions assumed in the theory and FEA that the elastic deformation of the porous matrix regions is equivalent to that of the solid continuous structure. Overall, the theory and the computational simulation can predict the experimental very well.

4 Conclusion

Novel reinforced scaffolds were developed by introducing a beam and a shell type reinforcements. The compressive modulus was effectively improved by the reinforcements. It was also found that the simple linear elastic theory and 3-D FEA can predict the modulus very well.

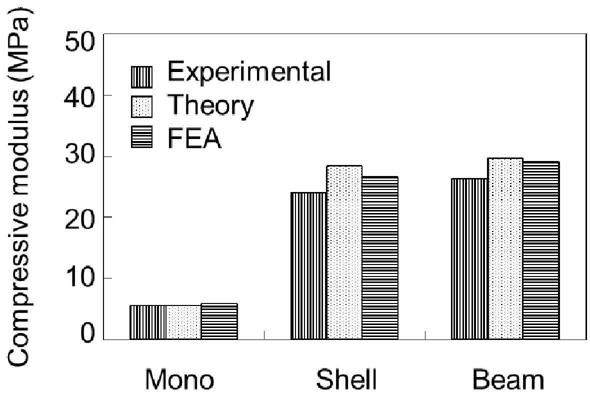


Fig.3. Comparison of compressive modulus

References

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