Effects of UV laser Parameters on Fabricating Three-Dimensional Poly(propylene fumarate) Scaffolds with Controlled Macropores Using Stereolithography

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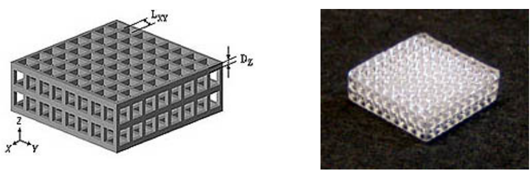
Introduction: Stereolithography (SLA) in combination with using UV-curable biodegradable polymers has become an attractive method of fabricating complex three-dimensional (3D) tissue engineering scaffolds having defined pore size and geometry.[1] Furthermore, the ability to control scaffold microarchitecture increases the spectrum of features that can be included in the scaffold design.[2] In this study, the effects of UV laser parameters on fabricating three-dimensional (3D) poly(propylene fumarate) (PPF) scaffolds with controlled macropores using SLA have been investigated.

Methods: 3D scaffolds were designed as an orthogonal cubic-lattice disk with square pores, which had fixed external dimensions (1 cm × 1 cm × 0.3 cm) and strut thicknesses (300 µm) in CAD software (Figure 1.). The range of pore sizes for final scaffold models was from 400 to 1000 µm. A photo-crosslinkable polymer resin was prepared by mixing the PPF (number-average molecular weight: 2313 g/mol) with diethylene fumarate (DEF) as a solvent, and then adding bis(2,4,6-trimethylbenzoyl)-phosphine oxide (BAPO) as a photoinitiator. Based on prior studies[1,3], a PPF:DEF ratio of 120 g of PPF (60% w/w) to 80 g of DEF (40% w/w) was added to 10mg/g solution of BAPO. The viscosity of the mixture at 25 °C was 1.8 Pa·s. Stereolithography (STL) files were used to design supports and 2D sliced data (BFF) files with 0.0508 mm layer thickness in 3D Lightyear software. BFF files were imported to the Viper SLA system (3D Systems, Valencia, CA) for fabricating 3D scaffolds by photo-crosslinking PPF resins layer-by-layer with a UV laser and user defined control parameters. To examine the effects of UV laser parameters, sample scaffolds with a target pore size of 670 µm were fabricated from different ranges of laser energy (E_c) (5-15 mJ/cm^2) and penetration depth (D_p) (3-10 mm). After fabrication in the SLA, supports were removed with a razor blade and scaffolds were rinsed with 100% ethanol several times to remove excess PPF resin trapped inside. In the final step, scaffolds were dried completely at ambient temperature and placed into the UV box for 1 hr. Mean pore sizes of each scaffold in the xy-plane and z-axis were measured using scanning electron microscopy.

Results/Discussion: The CAD design corresponding to controlled macropores and the fabricated scaffold made from SLA are shown in Figures 1a and 1b, respectively.



(a) (b)

Figure 1: (a) CAD model and (b) the corresponding scaffold fabricated from SLA.

We discovered that the mean pore size varied significantly, depending on the axis. As shown in Figure 2, the xy-plane mean pore sizes reproduced the CAD model with acceptable accuracy. But, in the z-axis the mean pore sizes were consistently smaller than the CAD model. This was a result of an overcure of each layer in the z-axis. It can be seen in Figure 3 that E_c and D_p values in SLA itself affect mean pore size variations of PPF scaffolds in the z-axis. At lower values, mean pore sizes in the z-axis were closer to the CAD intention, as compared to higher values of E_c and D_p.

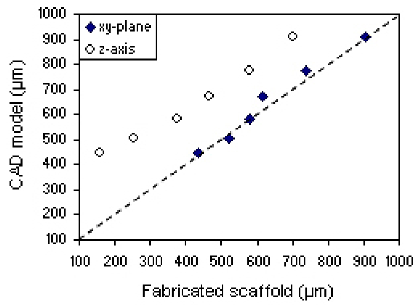


Figure 2: Mean pore sizes of CAD model and fabricated scaffold in two different axes. The dashed line indicates exact matching between the CAD model and the scaffold.

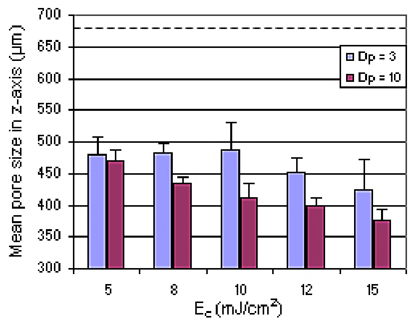


Figure 3: Mean pore sizes in the z-axis of PPF scaffolds made from SLA with different E_c and D_p values. The dashed line indicates a target pore size of 670 µm.

Conclusions: SLA remains an effective fabrication technique for highly complex 3D scaffolds. Features in the xy-plane are faithfully constructed according to the CAD design. However, controlling the z-axis overcure will be required for closer adherence to the internal architecture designed via the CAD software.

References

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