Biodegradable Composite Scaffolds Produced by Selective Laser Sintering

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Introduction

Tissue engineering (TE) generally requires the use of biocompatible and biodegradable 3D scaffolds for cell attachment and tissue regeneration. Composite scaffolds combine the advantages of biodegradable polymers and bioactive ceramics to fulfill various requirements, especially for bone tissue engineering. Rapid prototyping (RP) techniques are now used to produce TE scaffolds. Selective laser sintering (SLS) is one of the most effective and versatile RP techniques. It has been used to make composite scaffolds from hydroxyapatite (HAp)-poly(ether-ether-ketone) (PEEK) (Tan KH, et al., Proc I Mech Eng H. 2005; 219:183-194). However, PEEK is non-biodegradable, limiting its usefulness in TE applications. Nowadays, fabrication of bioactive and biodegradable TE scaffolds via SLS is still a challenge because commercial SLS machines require a large amount of powders of appropriate particle sizes. To address this problem, modifications of a Sinterstation™ 2000 (3D Systems, Valencia, CA) machine were made (Zhou WY, et al, Key Engg Mater, 2006; Vol.334-335: in press). With the modified machine, it is now possible to fabricate carbonated HA (CHAp)/poly(L-lactide) (PLLA) composite scaffolds using a small quantity of powders.

Materials and Methods

The PLLA used was commercially available (100L 1A, from Lakeshore Biomaterials, USA). CHAp nanospheres were synthesized through nanoemulsion (Zhou WY, et al., J Mater Sci-Mater M. 2006; in press). CHAp/PLLA microspheres were made using the solid-in-oil-in-water (S/O/W) emulsion solvent evaporation technique (Zhou WY, et al., Key Engg Mater, 2006, in press).

A miniature sintering platform, which consists of two small powder supply tanks, one small build cylinder and recycle bins, was fabricated in-house and installed in the build cylinder of the existing Sinterstation™ 2000 system. In the sintering process, the original powder supply tanks were empty and the biomaterial powders were fed from the miniature powder supply tanks by separate stepping motors. Other sintering parameters were controlled through the existing Sinterstation™ 2000 system.

Results and Discussion

The nanoemulsion technique produced spherical, nano-sized CHAp particles with diameters ~20 nm. The CHAp/PLLA nanocomposite microspheres fabricated were mainly in the size range of 5-30 µm despite changes in the CHAp content, which are suitable for the SLS process. Microstructural examination showed that the CHAp nanospheres were encapsulated within the PLLA microsphere to form a nanocomposite structure.

Isotropic 3D porous scaffolds, as shown in Fig.1, were designed by an extrude-cut channel patterning in three dimensions using SolidWorks®. The scaffold design parameters are listed in Table 1.

Fig.1 Scaffold design

Table 1 Scaffold design parameters

Type	Macroscopic Cube Size (mm)	Channel Width (µm)	Pillar Width (µm)	Designed Porosity (%)
A	8.0x8.0x16.0	800	300	78.4
B	6.6x6.6x13.2	600		70.0
C	5.2x5.2x10.4	400		55.8

Nanocomposite scaffolds were successfully sintered using the modified SLS machine. The sintering conditions are showed in Table 2, in comparison with sintering conditions of DuraForm® PA (a standard SLS material).

Table 2 Sintering conditions for CHAp/PLLA and PA

Sintering Condition	CHAp/PLLA	PA
Scan Spacing (mm)	0.08	0.15
Part Bed Temperature (°C)	60	160
Layer Thickness (mm)	0.08	0.10
Roller Speed (mm/s)	127	127
Scan Speed (mm/s)	1257	1257
Stepping Motor Delay (ms)	160	N/A
Fill Laser Power (W)	7-19	7-9

Fig.2 exhibits a photo of one sintered CHAp/PLLA nanocomposite scaffold. Loose powders entrapped inside of the scaffolds were easily taken out by manual shaking and brushing, without the use of a compressed-air jet.

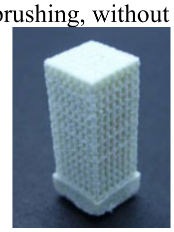

Fig.2 A photo of a sintered scaffold

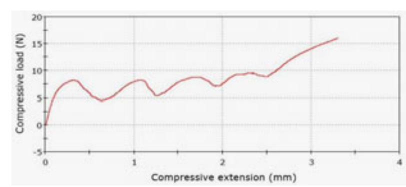

Fig. 3 Compression curve of a sintered scaffold

Fig. 3 shows a wavy compression curve of an SLS nanocomposite scaffold tested at a low crosshead speed of 0.5 mm/min. The wavy curve is probably due to consecutive collapses of the layers of the sintered scaffold. The finite element analysis (FEA) of SLS scaffolds showed a multi-level displacement model which agreed with the actual deformation curves of the CHAp/PLLA nanocomposite scaffolds.

Conclusions

With the miniature sintering platform, 3D isotropic scaffolds were successfully fabricated from CHAp/PLLA nanocomposite microspheres using the SLS technique. These sintered bioactive and biodegradable scaffolds should be suitable for bone tissue engineering.

Acknowledgement

This work was supported by a CERG grant (HKU 7118/05E) from the Hong Kong Research Grants Council.