TUNABLE DESIGN AND STRUCTURE-PROPERTY CORRELATIONS OF CORE-SHELL COMPOSITE SCAFFOLDS OBTAINED BY 3D-PRINTING

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Abbreviations

PLA: poly(lactic acid); FDM: fused deposition modeling
SC: simple cubic; ST: simple tetragonal;
BCC: body-centered cubic; FCC: face-centered cubic.

Introduction

Composite scaffolds combine the advantages of different biomaterials, thus better addressing the multiple needs of tissue engineering. In this work, we developed and characterized bioresorbable hybrid scaffolds composed of a 3D-printed PLA lattice core grafted with a bioactive hydrogel shell. While the core provides mechanical support, the hydrogel supports cell proliferation and osteogenic differentiation [1,2].
Moreover, the core-shell design and the use of additive manufacturing make this approach highly versatile, allowing to tailor the mechanical and functional properties of the scaffolds by varying the core/shell ratio and the lattice structure. The correlations between the mechanical properties of the scaffolds and their structure are here described according to Gibson-Ashby models for cellular solids [3].

Methods

Core specimens (10 x 10 x 10 mm^3) were designed as lattice structures with fixed strut thickness but variable unit cell type (Table 1) and dimensions. They were 3D-printed by FDM of PLA, immersed at 40°C in a gelatin-chitosan hydrogel solution, freeze-dried and post-cured.

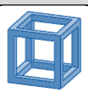
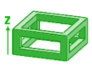
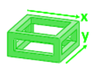
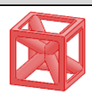
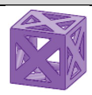
SC	ST z	ST xy	BCC	FCC
				
n = 1.11	n = 1.83	n = 1	n = 1.39	n = 1.46

Table 1: Lattice unit cells and corresponding values of the exponent n in power law fits (eq. 1) of relative modulus vs. *relative density curves; for ST lattices different loading directions are considered (z and xy).*

Core and core-shell specimens were subjected to morphological and physical-mechanical analyses (optical and scanning electron microscopy; hydrogel content and water uptake evaluation; compression tests). Core-shell scaffolds were immersed in distilled water for 24 h before compression.
Theoretical hydrogel content values were predicted on the basis of the void volume fraction in the core and of the porous hydrogel density. Data-driven models of mechanical properties were obtained by power law fitting (eq. 1) of curves reporting relative modulus (E_{rel}) or relative strength (σ_{rel}) against relative density (ρ_{rel}), evaluating each relative property as ratio between that of a lattice and that of bulk PLA.

$$E_{rel}\ (\text{or}\ \sigma_{rel}) = C\rho_{rel}^{\,n} \qquad (1)$$

Results and discussion

The appearance of a core and a core-shell specimen is displayed in Figure 1a. Noteworthily, the hydrogel fills all the void volume in the core and develops a highly interconnected porosity after freeze-drying, which is fundamental to ensure cell colonization.

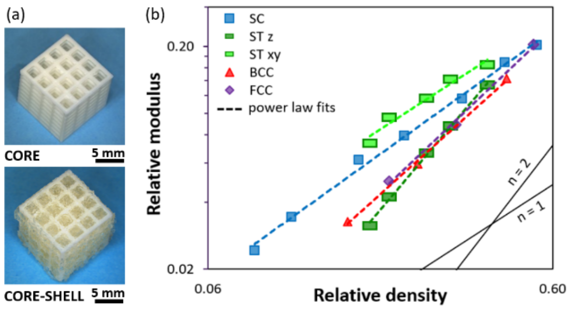


Figure 1: (a) Photographs of a lattice core and a core-shell scaffold with SC lattice structure. (b) Relative modulus vs. *relative density curves for different lattices; all curves are fitted with a power law model (eq. 1).*

By changing the lattice cell type and dimensions, core void volume fractions between about 45% and 90% are obtained. These values correspond to a wide range of bioactive hydrogel content (5÷50 wt% ca.) and water uptake. On the other hand, they also affect the stiffness and strength of the scaffolds, which resemble those of different types of spongy bone tissue. A proper balance between hydrogel content and mechanical properties should be found according to the specific target tissue.
Looking for guidelines to exploit the scaffold property tunability, the hydrogel content can be estimated through theoretical predictions, showing good consistency with the experimental values. Moreover, it is possible to outline data-driven structure-property correlations like those in Figure 1b, showing the power law relationship between relative modulus and relative density for scaffolds with different lattice types. Interestingly, the slope of these curves also indicates whether the lattice deformation behavior is mainly dominated by stretching (n = 1) or by bending (n = 2).

References

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2. Dey K et al, Macromol Biosci, 19(8):1900099, 2019.
3. Ashby M F et al, Cell Ceram Struct Manuf Prop Appl, Wiley-VCH, Weinheim, 2005: pp. 1–17