INVESTIGATION OF INFLUENCE OF INTERNAL ARCHITECTURE ON MECHANICAL PROPERTIES OF 3D PRINTED SCAFFOLDS FOR BONE TISSUE ENGINEERING

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Abstract

The aim of the study was to investigate the influence of internal architecture of 3D printed scaffolds on their mechanical properties. The polycaprolactone scaffolds with four different geometries produced by rapid prototyping were tested in this study. The 3D samples were manufactured with different internal architecture. The scaffolds were plotted using a 330 μm dispensing needle, layer by layer with lay-down pattern of the fibers: $0^0/45^0/90^0$, $0^0/60^0/120^0$, $0^0/90^0/180^0$ and $0^0/60^0/120^0$ with shifted layers. Scanning electron microscopy analyses and mechanical properties examinations were performed. The mechanical test showed that the highest Young's modulus was obtained for the samples with $0^0/60^0/120^0$ lay-down pattern, especially after layers shifting. The SEM analyzes didn't show any defects or layers delamination in the scaffolds. All the samples were characterized by appropriate 3D architecture and good layers connections.

The obtained results confirmed the hypothesis that scaffolds with $0^0/60^0/120^0$ lay-down pattern of the fibers and with shifted layers have the highest mechanically properties of the investigated samples and therefore, show high potential to be used in bone tissue engineering application.

Keywords: *Scaffolds, internal architecture, polycaprolactone,*

[Engineering of Biomaterials, 116-117, (2012), 8-9]

Introduction

Fabrication of scaffolds for tissue engineering becomes a very popular research topic in present days. There are several fabrication methods currently used for creating 3D porous structures with high porosity and interconnected pores. A rapid prototyping (RP) is one of the most interesting one. It allows for fabrication scaffolds with predesigned external geometry and internal architecture as well as required mechanical properties.

The aim of this study was to create and evaluate a polymeric 3D printed scaffold with different internal architecture which could be used for bone tissue engineering. The influence of internal architecture on mechanical properties of the samples was investigated.

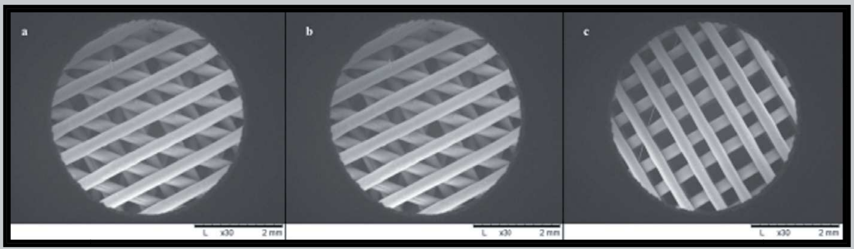

FIG. 2. Scanning Electron Microscopy (SEM) images of samples with internal architecture a) 00/450/900, b) $60^0/120^0$, c) $90^0/180^0$. Top view.

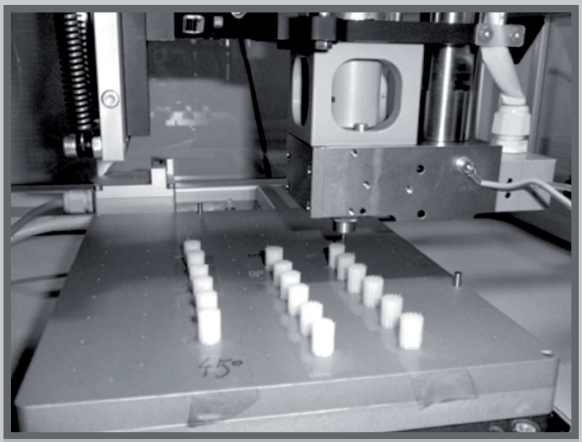

FIG. 1. Samples manufactured using Bioscaffolder® machine (SYSENG, Germany).

Materials and methods

Cylindrical porous scaffold (height: 4mm, diameter: 6mm) with three-dimensional orthogonal periodic porous architectures, were manufactured by Bioscaffolder® machine (SYSENG, Germany) from ε-polycaprolactone granulate (Sigma Aldrich PCL, average Mn ca. 80 000), (FIG.1).The melted polymer was plotted with a 330μm dispensing needle layer by layer, with lay-down pattern of the fibers: $0^0/45^0/90^0$, $0^0/60^0/120^0$, $0^0/90^0/180^0$ and $0^0/60^0/120^0$ with shifted layers. The temperature of the fabrication process was between 90^0 and 100^0C. After the samples were fabricated, their 3D structure and internal architecture were investigated by scanning electron microscopy (HITACHI TM1000 and HITACHI SU8000) and microCT (SkyScan 1172). Then, compression tests of the samples were carried out using Zwick material tester (Zwick Z005) at a cross-head speed of 1mm/min up to 50% of compressive strain.

Results and discussion

The SEM observations of the microfibers scaffolds showed a well-defined internal geometry with regular interconnected pores of dimensions between 300 and 400 μm, as well as uniform distribution (FIG. 2). The extruded filaments had a regular circular geometry with diameter of 300 μm, corresponding to the used nozzle tip (330 μm) (FIG. 2 a,b,c). Delaminating of the layers wasn't noticed (FIG. 3).

The compression tests were performed to show the influence of internal architecture on mechanical properties of the scaffolds. Mechanical properties analysis showed big differences in elastic modulus between the tested scaffolds (TAB. 1). For the scaffolds without shifted layers Young modulus was the highest for the lay-down pattern of $60^0/120^0$ and it was 51.8 MPa The E modulus for the scaffold with the orientation of $0^0/45^0/90^0$ was only 33.8 MPa. The connections between layers remained consistent under compression in all the tested scaffolds.

Conclusions

The study demonstrates that PCL scaffolds with shifted layers with internal orientation $60^0/120^0$ have the best mechanical properties among tested samples. The shifting of the layers could also improve cell adhesion do the scaffolds by change internal architecture .This type of scaffold can be applied to produce highly functionalized 3D construct for bone tissue engineering aplications.

References

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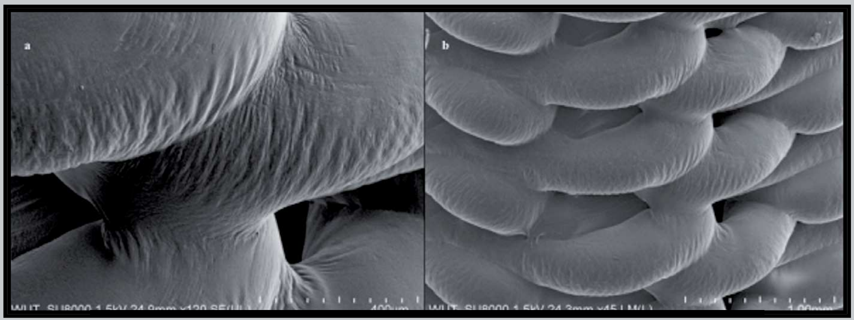

FIG. 3. Scanning Electron Microscopy (SEM) images of scaffold with orientation 600/1200 after shifted layers. Side view.

TABLE 1. Mechanical properties of investigated samples.

Name	E [MPa]	Re0,02 [MPa]	Rm [MPa]	R2
G23_45	33.8	2,7	4.7	0.99999
G23_60	51.8	2.8	5.3	0.99998
G23_60sh1	59.3	3	5.9	0.99998
G23_90	45.2	2.8	4.9	0.99998

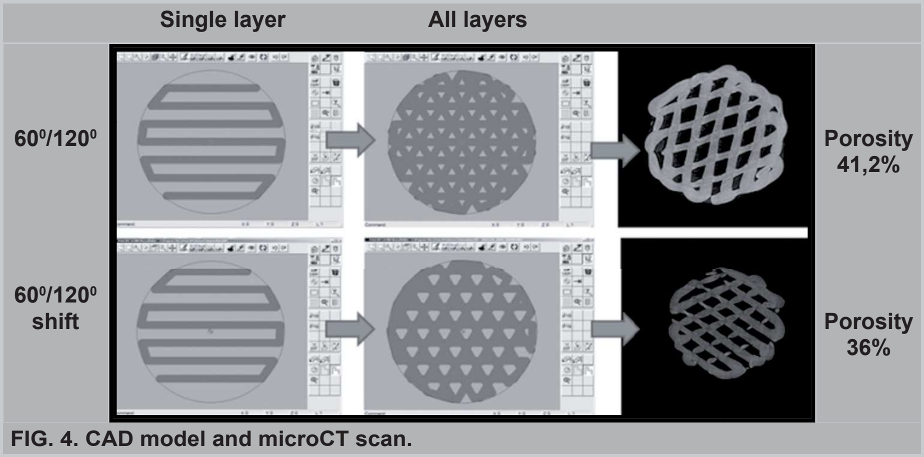

FIG. 4. CAD model and microCT scan.

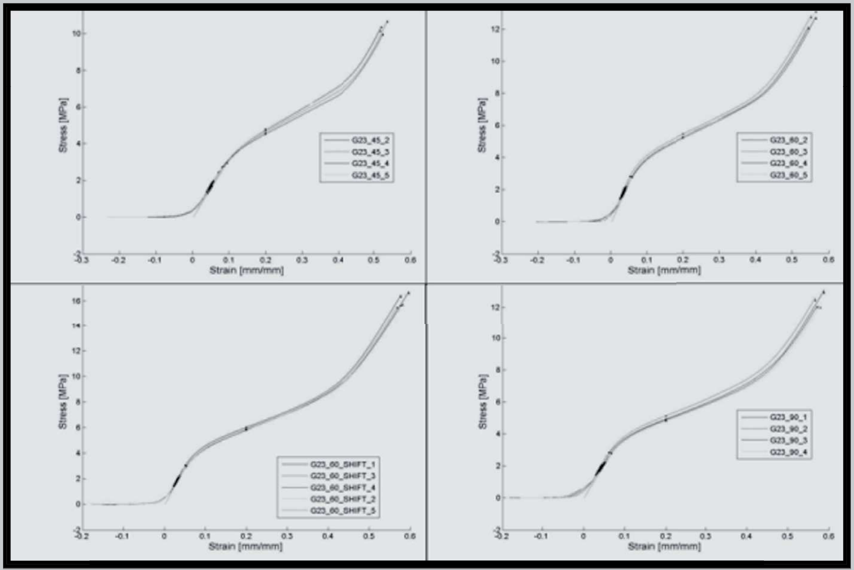

FIG. 5. Results of compression tests for the samples with different fibers orientations: a) $0^0/45^0/90^0$, b) $60^0/120^0$, c) $90^0/180^0$, d) $60^0/120^0$ with shifted layers.