Novel procedure to design 3D printed composite scaffolds for trabecular bone regeneration

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***Abstract*— The main challenge in regenerating bone defects is to create scaffolds with properties, particularly mechanical ones, in the range of the native tissue performance. In this study we evaluated, by Finite Element Analysis (FEA), the influence of materials and geometrical parameters on the mechanical performance of a novel PCL/Bioglass scaffold for bone tissue regeneration. The different architectures were firstly realized by Computer-Aided Design (CAD) software, then used to simulate compression test with FEA, according to ASTM standard. The different combinations of materials (described by Young's modulus and Poisson's ratio), together with geometrical parameters (e.g. fiber and pore size, layer orientation), were used as inputs for FEA. The output was the compressive modulus of each scaffold. The design procedure was characterized by two innovative aspects. The first one was to strictly relate CAD step to the current possibilities of the manufacturing technology. The second aspect was to apply the Taguchi method at the very beginning of FEA, with the aim of anticipating the optimization of the scaffold design before the experimental phase. Thanks to this design procedure, it was found out a relation between geometrical/material parameters and scaffold performance which guides its physical realization.**

***Keywords*—Scaffold; Design Optimization; Taguchi method; Finite Element Analysis**

I. Introduction

ONE of the current innovative treatments for segmental bone defects (SBDs) is to use artificial scaffolds to overcome the problems associated with autologous bone grafts. A wide range of synthetic materials has been proposed. In this perspective, 3D composite scaffolds made of a polymeric matrix loaded with an inorganic phase are of increasing interest in bone tissue regeneration [1]. The aim of this study was to evaluate the influence of material and geometrical parameters on the mechanical behaviour of novel PCL/Bioglass scaffolds, prior to take on their manufacturing, in order to have as much control as possible on their performances, with spare of time and costs.

Different scaffold architectures, obtained by the combination of geometrical inputs linked to the manufacturing technique (3D printing) and to the literature, were realized by CAD software.

CAD models were then imported in a FEA program firstly to validate them against experimental compressive testing and then to reveal a relation between material/geometrical parameters and mechanical performance of the scaffolds, thus to optimize them for 3D printing.

II. Materials and Methods

The main geometrical input parameters of the scaffold architecture were fibre diameter (330 and 840 µm), pore size (300, 450 and 600 µm), layer orientation (45, 60 and 90°) and offset of consecutive planes with the same orientation (Figure 1). They are chosen combining literature suggestions in the field [2]-[3] with the manufacturing technique, which is Fused Deposition Modeling (FDM) by a 3D Discovery printer (RegenHU, Switzerland).

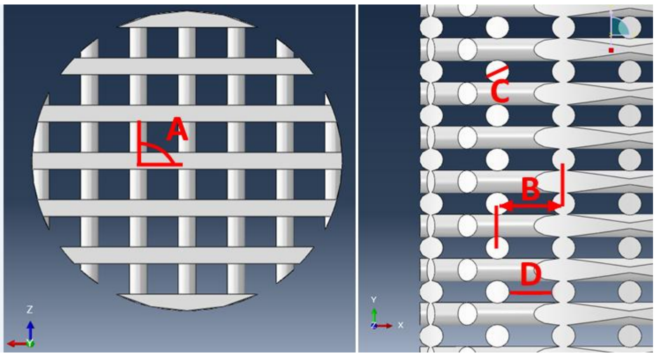

Figure 1. Geometrical input parameters of the scaffold: layer orientation (A), offset (B), fibre diameter (C) and pore size (D).

The different scaffold architectures, obtained combining the above parameters, were realized by CAD software. Thanks to CAD calculations it was possible to compress the geometrical manufacturing parameters into global characteristics, such as fibre/pore diameter ratio [4], in order to control scaffold porosity [5].

CAD models were imported in a FEA software (Abaqus, Simulia) to simulate their compressive performance according to standard [6]. Material was modelled as isotropic, linear elastic. Young's modulus and Poisson ratio were spanned in a wide range, both to cover the values generally attributed to polymer/bioglass composites and to obtain scaffold performances closed to the trabecular bone. By Taguchi method, all the possible factorial combinations of geometrical and material parameters were reduced to the

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principal ones, which were selected as inputs for the FEA simulations.

Finally, PCL/Bioactive glass material with specific composition was realized by mixing PCL pellets and Bioactive glass powders with innovative formulation (BGMIX_Mg [7], size < 20 µm). It was tested by indentation to obtain fibre material properties and then plotted in scaffolds. These were tested by compression [6] in order to validate the FEA simulations.

III. Results and Discussion

36 different architectures were obtained combining the geometrical manufacturing parameters. By porosity control, the architectures with fibre diameter of 840 µm were rejected, reducing the number of geometrical models at 18. The selected geometrical parameters, together with the material ones at three different levels (low, medium and high values of Young's modulus and Poisson's ratio) would give 162 combinations. Applying the Taguchi method they were reduced to only 18, which underwent simulation. FEA output suggested, e.g. for PCL/Bioglass combination of 70/30 wt.%, that the architectures with fibre diameter of 330 µm, pore size 300 µm, regardless the fibers orientation, could be able to reach the compressive behavior of trabecular bone.

IV. Conclusion

It was proposed an innovative procedure to design and control the porosity and mechanical performance of scaffolds for tissue regeneration. It has been proved for 3D printing and bone regeneration, but it is suggested for various kinds of manufacturing and tissue engineering applications.

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