

4.2.19. NON-DESTRUCTIVE CHARACTERISATION OF THE INFLUENCE OF SURFACE MODIFICATION ON THE MORPHOLOGY AND MECHANICAL BEHAVIOUR OF RAPID PROTOTYPED Ti₆Al₄V BONE TISSUE ENGINEERING SCAFFOLDS

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Introduction. Bone tissue engineering (TE) is a multidisciplinary field of science that puts efforts in designing and developing smart constructs for the healing of large bone defects [1, 2]. These constructs mostly consist of a combination of a porous structure based on biocompatible materials with cells to support cell seeding an *in vivo* implantation [3]. In TE, the tendency is to evolve from the use of open porous foams with a random structure to scaffolds with a complex, but highly controllable designed morphology that can be useful for the production of a new generation of bone implants [3, 4]. Selective laser melting (SLM), a relatively young rapid prototyping technique, offers the opportunity to produce micro-porous structures with morphological properties that are not random, but highly controlled through robust computer design [4, 5]. Many different parameters influence the cell behaviour within a scaffold and the strut surface roughness (SSR) is one of them [6]. Despite the advantage of SLM to allow a high control of the morphology, at this moment functional constraints caused by working close to the technical device limits prevent production of 3D porous scaffolds with a desired and controlled surface morphology. Therefore, a modification of the SSR after production is needed according to the cell response during culturing obtained via cell behaviour modelling and direct *in vitro* biological experiments [6]. It is obvious that any surface modification performed after production will change the topography of the struts surface as well as the mechanical properties both locally and of the global structure. Thus, the influence of the applied struts surface roughness reduction (SSRR) procedures on the morphology and the mechanical behaviour of the scaffolds needs to be determined. In this study, the struts surface of open porous Ti₆Al₄V scaffolds produced by SLM [3] has been modified by chemical and electrochemical polishing and the combined use of microfocus X-ray computed tomography (micro-CT) with in-situ mechanical loading and advanced 3D images analysis [4, 7] is applied for the characterisation of the mechanical behaviour of the tested micro-porous structures prior to and after surface modification. For determining the influence of the SSRR procedure on the struts roughness, a non-destructive SEM-based measurement protocol is applied. The scaffolds morphology quantification of the as produced and surface modified scaffolds is done by micro-CT. Main aim of these experiments is the characterisation of the 3D SLM produced porous structures prior to and after surface modification in order to optimize the design, modelling and production and in the final stage to improve the properties of the scaffolds to be applied for bone regeneration.

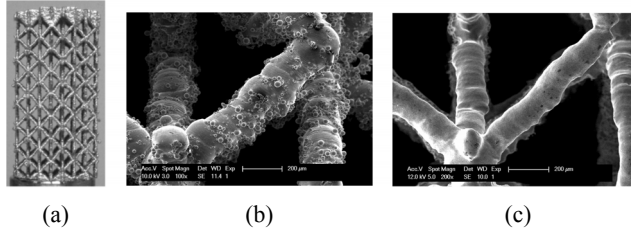


Fig 1. (a) An SLM produced open porous Ti₆Al₄V scaffold and a typical SEM image of a unit cell of an open porous Ti₆Al₄V scaffold (b) prior to surface modification, where non-melted powder grains are present on the surface and (c) after surface modification, showing a smooth surface

Results and discussion. The struts surface of the Ti₆Al₄V scaffolds after production (fig. 1a) reveals a large and highly inhomogeneous strut roughness caused by non-melted powder grains attached to the surface (fig. 1b). Therefore; an appropriate roughness reduction procedure is used, which apart from removing the inhomogeneities on the struts, allows to obtain a cell-friendly strut topology. Fig. 1B and 1C represent a SEM image of a unit cell of a typical open porous Ti₆Al₄V scaffold, produced by SLM, prior to and after surface modification respectively. It can be clearly observed that the applied surface modification treatment leads to a smooth strut surface, but decreases the strut diameter, which has an influence on the mechanical behaviour of the scaffolds.

As can be seen in table 1 and fig. 2, micro-CT based characterisation of the scaffolds reveals differences in morphology of the scaffolds before and after surface modification [3].

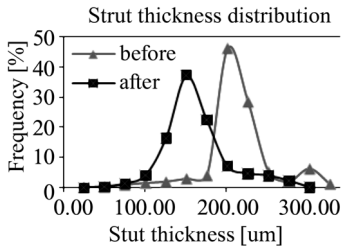


Fig. 2. Strut thickness distribution prior to and after surface modification

In-situ mechanical loading tests performed on the scaffolds prior to and after modification of the struts surface show the changes of the scaffolds mechanical properties in function of applied surface roughness reduction procedures (table 1).

Conclusions. Thorough characterisation of the morphological and mechanical changes in the scaffolds due to surface modification can be easily obtained by the micro-CT based investigation. This will result in the optimization

Table 1. Mechanical properties and microCT based morphological characteristics of the scaffolds prior to and after surface modification

Sample	Avg. strut thickness (μm)	Porosity (%)	Strain at max.load (%)	Strength (MPa)	Stiffness (MPa)
Before	213.81 ± 0.57	84.43 ± 0.14	6.04 ± 0.003	13.00 ± 0.62	397.07 ± 29.95
After	169.05 ± 7.58	91.03 ± 0.97	7.02 ± 0.002	7.41 ± 0.88	226.15 ± 22.45

of the surface modification protocol according to the desired morphological and mechanical properties. However, *in vitro* cell culturing experiments are needed to evaluate the relation between cell response and strut surface roughness. Combined use of micro-CT imaging, 3D image analysis and non-rigid image registration with in-situ mechanical loading can be applied in order to characterise the distribution of the most critical strains under compression and to compare the mechanical behaviour of the as produced and surface modified scaffolds as shown in Refs [4, 7].

Reference:

1. **Lenas, P.** et al. Developmental engineering: A new paradigm for the design and manufacturing of the cell-based products. Part I: from three-dimensional cell growth to biomimetics of in vivo development. *Tissue Engineering: Part B*, 15 (2009).
2. **Piskin, E.** Biomaterials in different forms for tissue engineering: an overview. *Materials science forum*, 250 (1997) 1 – 14.
3. **Karageorgiou V.** et al. Porosity of 3D biomaterial scaffolds and osteogenesis. *Biomaterials*, 26 (2005) 5474–5491.
4. **Kerckhofs, G.** et al. Mechanical characterization of porous structures by the combined use of micro-CT and in-situ loading. *World Conference on Non-Destructive Testing 2008*. Shanghai, 25-28 October 2008 WCNDT 2008 Proceedings Book.
5. **Van Bael, S.** et al. Morphological and mechanical characterization of Ti6Al4V scaffolds produced with Selective Laser Melting. *1st International Conference on Tissue Engineering (ICTE)*. Leiria – Portugal, 9 – 12 July 2009.
6. **Ponsonnet L.** et al. Effect of surface topography and chemistry on adhesion, orientation and growth of fibroblasts on nickel–titanium substrates. *Materials Science and Engineering C*, 21 (2002) 157 – 165.
7. **Kerckhofs, G.** et al. Experimental quantification of the local strains in bone TE scaffolds by the combined use of micro-CT imaging, in-situ loading and local strain mapping. *1st International Conference on Tissue Engineering (ICTE)*. Leiria – Portugal, 9 – 12 July 2009.