Additive Manufacturing Meets Medicine 2020

Infinite Science | Publishing

3D Additive manufacturing of shapeshifting scaffolds: polymeric and ceramic solutions

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Abstract: Scaffolds for cell growth have been growing in popularity in regenerative medicine. Typically, the scaffold structures are mechanically rigid or semi-rigid. This can be overcome using multiphoton laser lithography that allows the fabrication of flexible geometries out of hard material, making such structures appropriate for soft tissue application. Furthermore, the application of postprocessing with hybrid polymers results in new ceramic materials. This gives an option to produce new types of structures with combined mechanical stability at the microscale with flexibility at the macroscale.

I. Introduction

Recently there is an increased drive in the application of microporous scaffolds for *ex-vivo* cell cultivation. The interest lies in the fact that a live cell culture can be grown outside of a living organism and implanted into it later [1] or the growth mechanism of cancer cells [2] can be examined mimicking the conditions of a human body much better than in the 2D environment of a petri dish.

Different types of scaffolds have different properties depending on material and geometry. Achieving different geometries can be done with a technique called multiphoton laser lithography, which has been proven in different scenarios and geometries [3]. One of the materials that can be structured this way is known as SZ2080 [4]. After a precondensation step it is comprised of long inorganic chains of randomly arranged from -Si-O-Zr-containing "backbone" chains with cross-linkable methyl acrylate groups. This is a biocompatible material already proven in clinical trials with 3D scaffold structures [5].

It also features a property, wherein it can be post-processed thermally after laser structuring the produce new inorganic phases, such as glass and glass-ceramic phase while maintaining the original geometry [6]. Said phases are expected to be useful for bone tissue generation and similar applications in the context of ZrO_2 containing bioglasses [7]. However, they are usually not mechanically flexible, which is a desired feature achieved only for soft materials [8].

The scaffold type chosen here is of a "chainmail" geometry [9]. It is a flexible structure to some extent simulate soft tissue behavior [10]. We show that the thermal post-treatment applied to flexible scaffolds results in retained geometry, flexibility and a glass phase [6], difficult to achieve otherwise (Fig. 1).

II. Material and methods

The chainmail scaffolds produced here were made using a direct femtosecond laser writing setup "Laser Nanofactory" ("Femtika", Vilnius) with a pulse duration of ~250 fs, 1 MHz pulse repetition rate and 515 nm central wavelength and a 1.4 NA objective and exposure parameters tuned for the center of the fabrication window. The material used was SZ2080, which was drop cast on a coverslip and prebaked at 70 °C for 2h. After exposure samples were developed in methyl isobutyl ketone. Characterization was performed with an optical microscope.

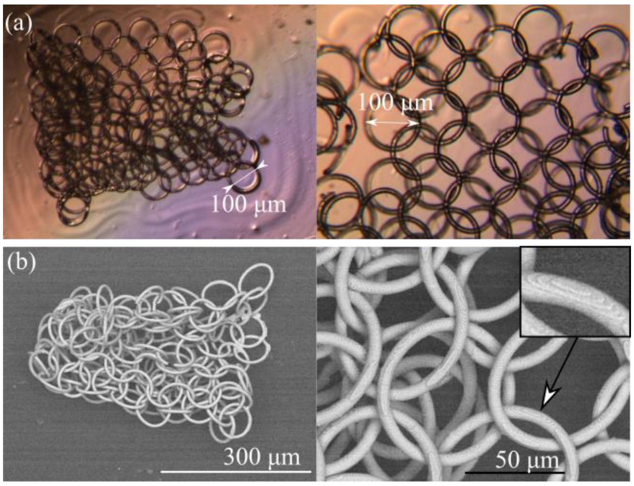

Figure 1: Chainmail scaffold microscope image before (a) and SEM micrograph after thermal post-treatment (b). Left are macro images and magnified images. The geometry and small features are retained. Inset in (b)-right shows the typical slicing defects retained from the printing process.

For post-treatment, the scaffolds were placed in a tube

DOI: 10.18416/AMMM.2020.2009010

furnace and heated to 1000 °C for 1h in an inert gas atmosphere. Afterward, the structures were investigated with a scanning electron microscope (SEM) to confirm the retention of small surface features.

III. Results and discussion

The resulting chainmail scaffolds are shown in Fig. 1(a) shows the structures as observed after developments showing the circular geometry of the links. In Fig 1(b) the heat-treated scaffold although, folded from handling, retains the ring shape the links. Shrinking down to 60% of the original dimensions is observed as expected from ref. [6] (see the diameter of rings in Fig. 1).

Furthermore, the main result here is that after the post-treatment even-microscale surface defects are maintained. This is indicative of the slicing defects shown in Fig. 1(b). Therefore, any desired surface modulation can be maintained during post-treatment. Engineered surface morphologies can remain without reflow and produce interesting cell adhesion effects.

In addition, the material phase expected here is known to be an inorganic glass phase dominated by amorphous SiO_2 with lesser traces of ZrO_2 [6], [11]. This is interesting because glass can be also used for tissue engineering. We suggest this because composite glasses have been used for bone tissue engineering [7]. Even glass-ceramic phases can be achieved if higher processing temperatures are used [6].

IV. Conclusions

In conclusion, new types of 3D flexible scaffolds are shown. The provided modified phase structures are expected to provide both new *ex-vivo* and *in-vivo* research environments, unexplored before.

For prospects, the glass-ceramic phase flexible scaffolds could be further investigated for use in bone tissue regenerations as ceramics are known to enhance osteoblast differentiation and proliferation [12]. The flexible scaffolds would not suffer the typical failures under mechanical stress [13] and could be remodeled to fit the implantation sight better in contrast to the static variations used currently.

ACKNOWLEDGMENTS

Research funding: The author state no funding involved.

AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest.

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