3D printing of hydrogel scaffolds based on poly(ethylene glycol) diacrylate

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Abstract: This is a case study for the development of a poly(ethylene glycol) diacrylate-based hydrogel for an additive manufacturing process. By introducing a photoinitiator and an UV absorber into the poly(ethylene glycol) diacrylate a spatially and temporally three-dimensional polymerization takes place. To demonstrate the possible printing resolution a scaffold is generated on a modified commercial stereolithography system.

I. Introduction

In biochemistry biocompatible materials for use in regenerative medicine are being researched with emphasis. For example, they can be used as basis for implants or scaffolds for cell colonization. The demand for these high-performance polymers is constantly growing as they have a broad property profile e.g. for tissue engineering [1-3]. Poly(ethylene glycol) diacrylate (PEGDA) is one of these polymers, which can be generated with a photoinitiator to a hydrogel [4-6]. This material is processed into a 3D structure with a specific architecture using a stereolithography (SLA) system [7,8]. The aim of this study is to demonstrate that a conventional SLA system is able to generate a useful scaffold from a hydrogel. The scaffold will serve as a scaffold with a large 3D surface. The small channels and undercuts can be used for e.g. cell colonization and nutrient delivery.

I.I. Stereolithography (SLA)

Stereolithography is an additive manufacturing technique based on photopolymerization of a resin by using UV laser radiation (e.g. 405 nm). In our case we us a commercial printer (*Nobel 1.0, XYZprinting, Inc. Taiwan*) with some technical modifications, shown in Figure 1 [9]. The known parameters are: a X-Y-resolution of 300 µm, a layer thickness of 25, 50 or 100 µm and a laser power range from 5 to 72 mW. All other parameters cannot be read from the system. In our experiments a few millilitres of photopolymer per formulation are required for basic investigations. Therefore, the system is modified with a smaller chamber. The commercial machine setup from Fig. 1; A received a new building platform (9) including a new connector (2) to z-stage (Fig. 1; B & C). Due to the magnetic mechanism (16) between the metallic building platform and the connector we are able to dismount the platform and print specific small and filigree samples (8). Also it is possible to observe the printed objects under the microscope (*VW-9000, Keyence Corp., Osaka, Japan*) without removing them from the metallic platform. The chamber (10) was modified geometrical to reduce the resin (5) volume and is fixed by a 3d-printed special unit (19). All other components like beamline (6, 7, 11, 12, 13) or the mechanical moving system (1, 3) are original components from the Nobel 1.0. Also the bottom of the chamber the optical window (17+18) is made by original material like the chamber from the commercial printer. In this way it is possible to use the original detachment mechanism of the system.

II. Material and methods

In order to demonstrate the efficiency of a technical system meaningful test specimens are required. First a CAD model is created and after that the object is manufactured by the SLA system. In a first step a cube with an edge length of 15 mm is designed in a CAD program SolidWorks 2017 (Dessault Systemes SolidWorks Corp., France) and then structural modified as STL-file in the software Materiallaise 3-matic Version 13 (Materialliese GmbH, Germany) (Figure 2). In the second step the cube is placed in a star-shaped pattern and converted into a lightweight structure. This creates a uniform framework structure (see Figure 3).

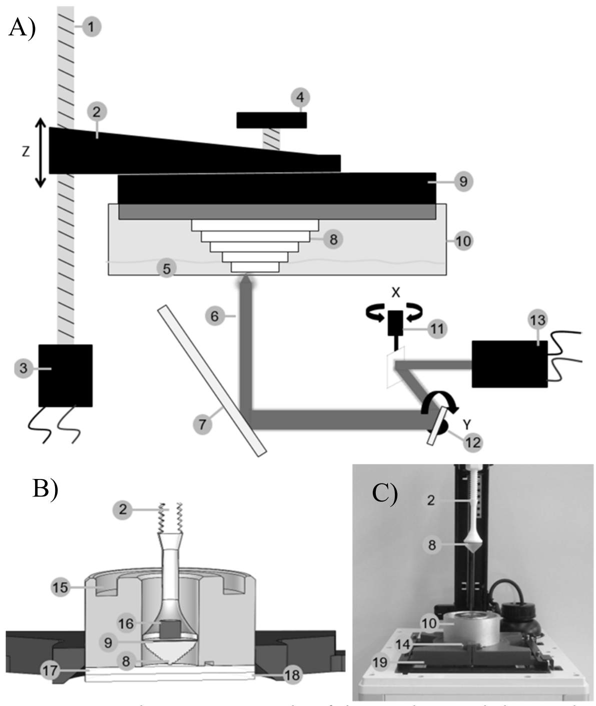

Figure 1: Schematic principle of the used stereolithography configuration A) original machine setup Nobel 1.0; B) CAD data modified chamber and modified building platform; C) photograph of the modified setup at Nobel 1.0 including a sample (8) [9]

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As resin, Poly(ethylene glycol) diacrylate with an average molecular weight of Mn 700 (Sigma Aldrich, Inc., U.S.A.) was intermixed for 6 h at 500 r.p.m. with the photoinitiator Omnirad 2022 (PI) (bis(2,4,6-trimethyl-benzoyl)-phenyl-phosphineoxide / 2-hydroxy-2-methyl-1-phenyl-propan-1- one) from IGM Resins B.V., Belgium. Subsequent the resin rests a period of one hour. Some further experiments showed that the best resin properties contain a PI concentration of 0.005 wt-% [9]. To reduce the curing depth on a suitable value, a UV radiation absorber (2,2'-dihydroxy-4,4'-dimethoxy-benzophenone) from TCI Deutschland GmbH was added in a value of 0,006 wt-%. The powder was intermixed at the PEGDA+PI resin for 12 h at 40 °C and 1000 r.p.m. The laser power intensity was set to 55 mW. The sample scaffold is generated with a layer height of 0.1 mm without any supporting structures and additional edges.

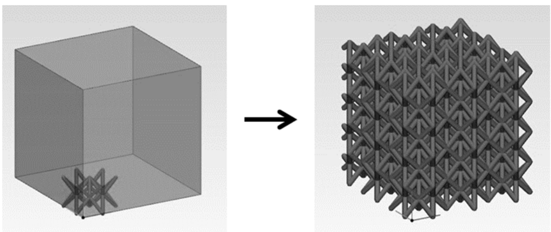

Figure 2: star like structure in the cubic body

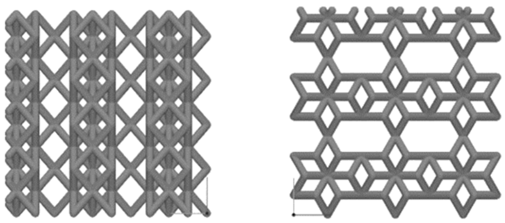

Figure 3: the light weight structure of the scaffold in different view positions

III. Results and discussion

A sample scaffold is shown in Figure 4. Details like the fine channels (d ≈ 500µm, see Fig. 4B, C) and undercuts are clearly visible and run through the entire 3D object. Furthermore, the individual layers are also very well recognizable.

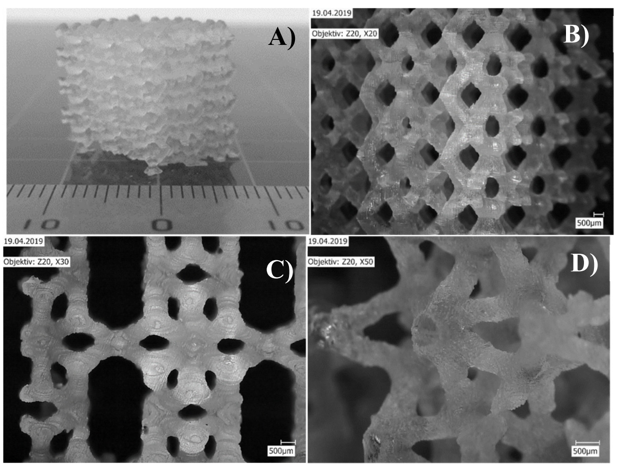

Figure 4: Representation of the filigree structure of the scaffold, A) overview, B) diagonal view, C) detail with continuous channels, D) filigree structure of a strut

With regards to the literature, the results obtained show that it makes sense to carry out further investigations on PEGDA-based hydrogels with different molecular weights (Mn) such as 400 Mn, 575 Mn, 1000 Mn and 2000 Mn. It is recommended to further investigate how the generation phase behaves during the printing process and how the material properties behave for all these hydrogels. In order to make a reliable statement about the mechanical behaviour or biocompatibility of the hydrogel thermal stress tests [10] should be carried out. But also cytotoxicity, influence on tissue damage and blood compatibility (hemocompatibility tests) have to be investigated.

IV. Conclusions

The scaffold printed with the described formula shows that a commercial SLA system makes it possible to generate highly filigree thin-walled and elastic 3D objects in one production step. The designed lightweight structure (only ≈ 15 % material in vol.) corresponds in structure to the scaffold produced on the SLA system (≈ 0.26 g/cm³). In order to make the sample parts even more filigree, the power intensities of the laser should be gradually increased from 5 mW to 55 mW in 5 mW steps. From our point of view, further tests have to be done.

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