Customizing the microstructure in three-dimensional Mg structures

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INTRODUCTION: 3D printing of degradable Mg implants opens new clinical possibilities. Besides the geometry and the chemistry, the microstructure is an important factor influencing the corrosion rate [1]. It is known for Selective Laser Melting (SLM) that process parameters have an effect on the grain structure [2]. We propose to use SLM for the production of implants with directed degradation by controlling the grain structure.

METHODS: A mandible plate (5 x 0.5 x 0.2 cm) and simple cubes (a = 5 mm) were designed with SolidWorks CAD software (Version 13). Two freeform objects were applied from thingiverse.com [3-4]. A modified SLM system (Realizer 100, MCP Realizer, Germany) with a 100 W fiber laser was used to additively manufacture the three-dimensional objects layer-by-layer under a protecting Ar atmosphere. xy-hatching strategy of laser trajectories in consecutive layers was applied, see arrows in Fig. 2a. Details can be found in [5]. AZ91 powder (SFM SA, Switzerland, particle size D_{10} 39.7 µm, D_{50} 59.0 µm, D_{90} 92.4 µm) was used as a starting material. The microstructure was metallographically investigated after grinding, polishing and etching with HNO_3/ethanol for 10 sec using a SEM (TM-3030Plus, Hitachi, Japan) and light microscope (Olympus BX61, Stream Motion 1.8 software). Grain size was determined by quantifying linear intercepts of grain boundaries along 700 µm lines.

Fig. 1: Freeform magnesium AZ91 structures, produced by Selective Laser Melting.

RESULTS: Figure 1 shows the produced freeform shapes (left) and the mandible plate (right). Due to its fine design and the low specific weight of Mg, this bone implant weighs only 0.62 g. Four distinct regions were determined in metallographic sections of SLM cubes (Fig. 2a), each consisting of typical grain sizes, see table 1. Interestingly, the microstructure is influenced by the laser trajectories (heat-affected zone in regions ②, ③ & ④) and the smallest grains are found where the starting laser induces the maximal energy and thus the highest temperature (region ①). A decoration with Mg particles is observed at the boundary. The corrosion of such cubes is heterogeneous and can be attributed to the different grain sizes.

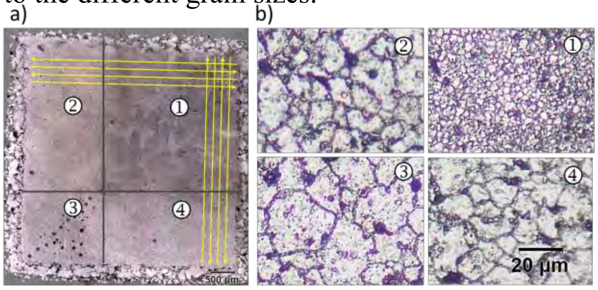

Fig. 2: Light microscopic images of SLM-Mg microsection a) overview incl. laser trajectories, b) details of regions ① - ④.

Table 1. Region–dependent grain size.

Region	Average grain size [µm]
①	3.5 ± 1.0
②	12.0 ± 0.4
③	15.1 ± 2.4
④	9.7 ± 0.5

DISCUSSION & CONCLUSIONS: SLM allows the fabrication of complex-shaped Mg structures. During the laser process, the solidification rate and thus the grain size and phases can be locally influenced due to different heat extraction. The SLM scanning strategy therefore could be used to locally control mechanical and corrosion properties, e.g. for prospective implants with directed degradation.

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