Intelligente Materialien
Nationales Forschungsprogramm NFP 62
Matériaux intelligents
Programme national de recherche PNR 62
Smart Materials
National Research Programme NRP 62

Properties of NiTi-Structures Fabricated by Selective Laser Melting

T. Bormann[1,2,3], R. Schumacher[1], B. Müller[2,3], M. Mertmann[4], U. Pieles[1] and M. de Wild[1]

[1] University of Applied Sciences Northwestern Switzerland, IMA, Muttenz, Switzerland. [2] School of Dental Medicine, University of Basel, Basel, Switzerland. [3] Biomaterials Science Center, University of Basel, Basel, Switzerland. [4] MEMRY GmbH, Weil am Rhein, Germany.

Introduction: Shape memory alloys (SMA) have exceptional properties as they can change their shape as the result of thermal or mechanical stimuli. Additionally, SMA's exhibit pseudo-elastic behaviour, an effect often used in stents for instance. The reason for these unique properties is a reversible switch between martensite and austenite crystallographic structures (see figs.1 and 2). This so-called martensitic phase transition takes place on the nanoscopic length scale and occurs without any diffusion processes.

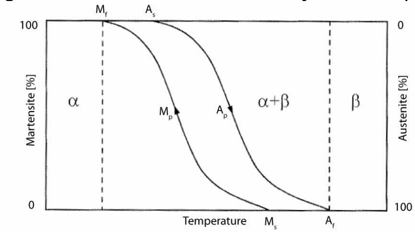

Fig. 1: Proportion of austenite β and martensite α phases in dependence of the temperature.[1]

One of the most widely used shape memory alloys is NiTi with approximately equiatomic composition. It`s phase transition can be adjusted in a medically relevant temperature range of -150 ℃ and 100 ℃. Due to their biocompatibility, NiTi-SMAs are successfully used in the field of biomedical engineering.[2] We demonstrate that selective laser melting (SLM) permits producing NiTi microstructures with the typical material properties of SMAs. By designing and optimizing of SMA structures, implants with advanced performance can be realized.

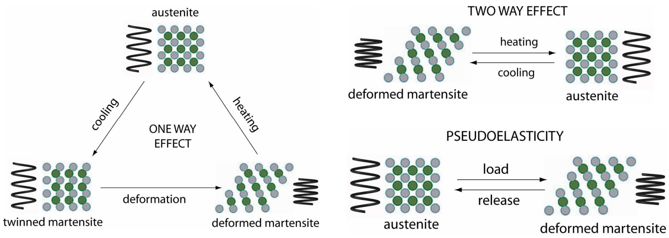

Fig. 2: Different effects in shape memory alloys.

Methods: For the preliminary study, pre-alloyed NiTi-powder (MEMRY GmbH) with a d_{50} value of 60 µm served for specimen fabrication. Differently designed test objects were built by means of the SLM Realizer 100 (MTT Technologies) operated with a continuous wave Ytterbium fibre laser (wavelength: 1068 - 1095 nm). Different energy densities of 80 – 100 J/mm³ have been used. Differential scanning calorimetry (DSC) was accomplished with the NiTi-powder and the SLM-structures. Measurements were performed between -100 ℃ and 125 ℃ using the DSC 30 (Mettler-Toledo). The one-way shape memory effect of the SLM structures was verified by mechanical expansion of a spiral spring followed by heating and measuring of the change of sample length. Additionally, microstructural investigations on SLM fabricated samples have been done by optical microscopy. Careful sample preparation included grinding, electropolishing and etching of the specimen.

Results and discussion: The pseudo-plastic behaviour of the SLM materials could clearly be demonstrated, as the one-way shape memory effect could be shown, see fig. 3.

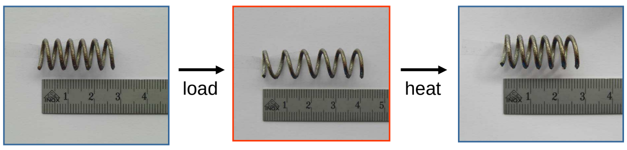

Fig. 3: One-way shape memory effect in SLM fabricated spring.

The NiTi-powder and the SLM-structures do show a phase transition in the related DSC measurements, see fig. 4. The austenite peak temperature A_p of the powder corresponds to 19 ℃, whereas the SLM-object exhibits a value of 35 ℃. The martensite peak temperature M_p lies at -4 ℃ for the powder and 0.2 ℃ for the SLM-structure.

By changing laser parameters towards higher energy densities, the austenite and martensite peak temperatures are shifted to higher values, see fig. 5. Since the phase transition temperature strongly depends on the Ni/Ti ratio[3], reasons might be loss of Ni during the laser melting process. Also Ni-rich segregations could be formed during manufacturing procedure.

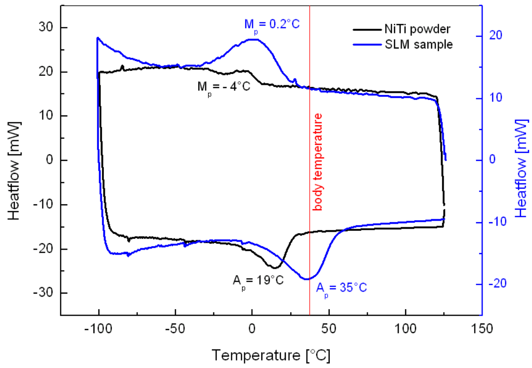

Fig. 4: DSC curves of NiTi powder and a SLM fabricated sample.

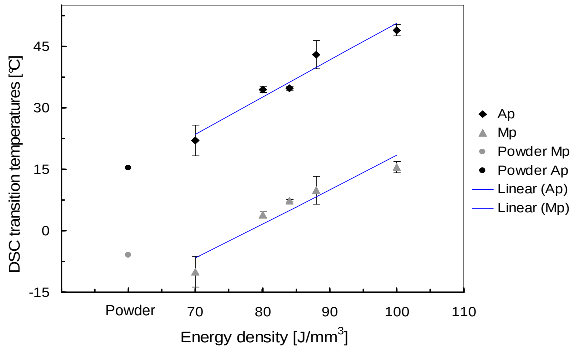

Fig. 5: Austenite and martensite peak temperatures of SLM samples fabricated with different energy densities of the laser.

Metallographic investigations of SLM samples show different microstructures within the SLM fabricated structures as shown in fig. 6. In the SLM fabricated specimen an oriented microstructure with elongated grains occurs. Elongation takes place in building direction and is the result of heat transfer processes. The support structure, which is located between sample volume and building platform, shows a granular microstructure due to smaller volume and an associated better heat conductance.[4]

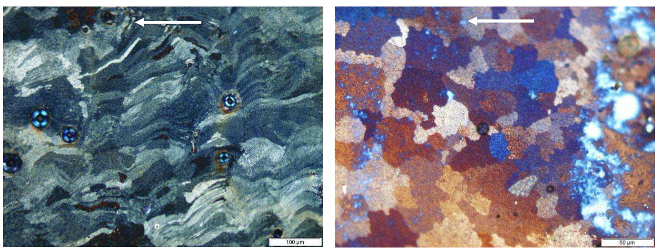

Fig. 6: Optical micrographs of the microstructure in SLM fabricated samples. Left: microstructure in the specimen, right: microstructure of supporting material. Arrows indicate building direction.

Conclusions: The preliminary experiments reveal that SLM is an appropriate method for the fabrication of constructs with shape memory phenomena. Optimizing this process, bone scaffolds and implants of complex morphology could be realized. The final aim is the production of SMA-implants for a great variety of applications and for the benefit of patients.

Acknowledgement: The multi-disciplinary team gratefully acknowledges the financial support of the Swiss National Science Foundation within the program NRP 62 'Smart Materials'.

Contact:
Therese Bormann
T +41 61 4674-796
therese.bormann@unibas.ch

Michael de Wild
T +41 61 467 4-695
michael.dewild@fhnw.ch

References: [1] Jafar Kallil Allafi (2002), Mikrostrukturelle Untersuchungen zum Einfluss von thermomechanischen Behandlungen auf die martensitischen Phasenumwandlungen an einer Ni-reichen NiTi-Formgedächtnislegierung. [2] ASTM International, F 2063-05. [3] W. Tang et al., (1999) Acta Mater 47: 3457-3468. [4] L. Thijs et al., (2010) Acta Mater 58: 3303-3312.