

Properties of NiTi-Structures Fabricated by Selective Laser Melting

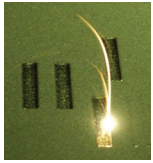
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INTRODUCTION



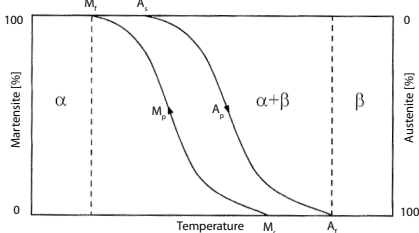
Shape memory alloys (SMA) have exceptional properties as they can change their shape as the result of thermal or mechanical stimuli. Additionally, SMA's exhibit pseudo-elastic behaviour, an effect often used in stents for instance. The reason for these unique properties is a reversible thermoelastic switch between martensite and austenite crystallographic structures, a so-called martensitic phase transition. One of the most widely used shape memory alloys is NiTi with approximately equiatomic composition. Its phase transition can be adjusted in a medically relevant temperature range of -150 °C and 100 °C. Due to their biocompatibility, NiTi-SMAs are successfully used in the field of biomedical engineering [1]. 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.

METHODS

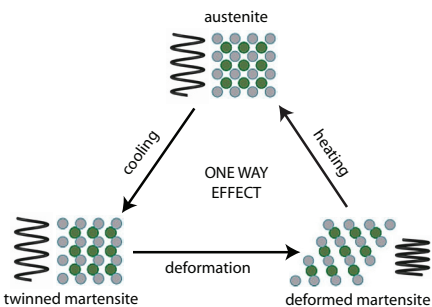
For the preliminary study, pre-alloyed NiTi-powder (MEMRY GmbH) with a d_{50} value of 60 μm served for specimen fabrication. Differently designed test objects were built by means of the SLM Realizer 100 (MTT Technologies) operated with a continuous wave Ytterbium fibre laser (wavelength: 1068 - 1095 nm). Different energy densities of 80 - 100 J/mm^3 have been used. Differential scanning calorimetry (DSC) was accomplished with the NiTi-powder and the SLM-structures. Measurements were performed between -100 °C and 125 °C 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.

SHAPE MEMORY EFFECTS

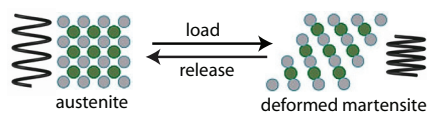
The shape memory effect is caused by a so-called martensitic phase transition. The low temperature martensite phase transforms above a certain temperature range into the high temperature austenite phase, as illustrated in the figure below [2].



If martensitic NiTi material is deformed, the atoms of the martensite phase are displaced in the nano-scale what resulting in plastic strain. Upon heating of the material above the transition temperature range, the deformed martensite transforms into austenite. Result is the recovery of the original macroscopic shape, as shown in the figure below.

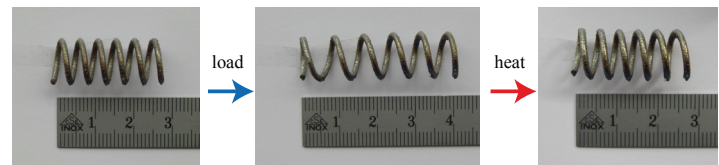


In pseudoelastic NiTi, the material is stable in the austenite phase and upon loading, stress-induced martensite is formed. Upon unloading, the martensite is immediately re-transformed into austenite, resulting in shape-recovery.



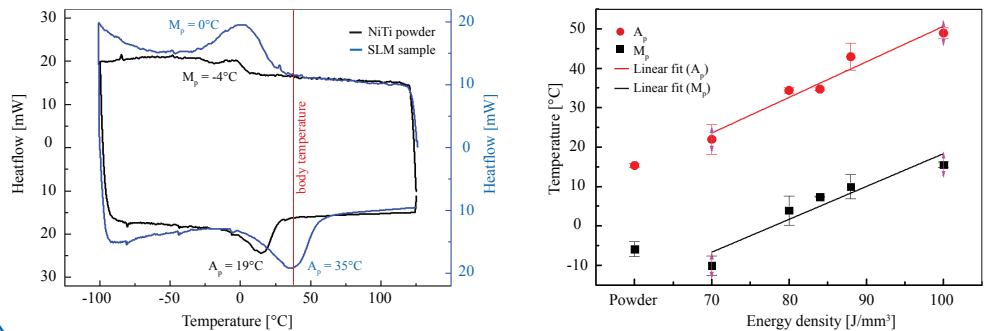
ONE WAY EFFECT IN SLM FABRICATED SAMPLES

As shown in the pictures at the right hand side, the one way shape memory effect in our SLM fabricated samples can clearly be seen. That demonstrates the pseudo-plastic behaviour of our samples.



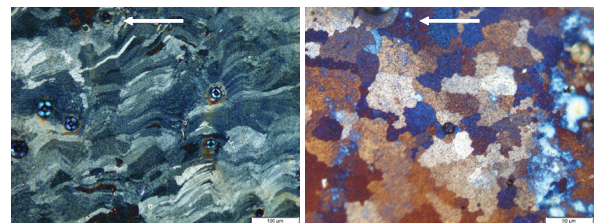
DSC AND SLM-PARAMETERS

The NiTi-powder and the SLM-structures do show a phase transition, as shown in the DSC measurements pictured in the diagram below. The austenite peak temperature A_p of the powder corresponds to 19 °C, whereas the SLM-object exhibits a value of 35 °C. The martensite peak temperature M_p lies at -4 °C for the powder and 0 °C for the SLM-structure. By changing laser parameters towards higher energy densities, the austenite and martensite peak temperatures are shifted to higher values, as can be seen from the diagram on the right hand side. 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.



METALLOGRAPHY

Metallographic investigations of SLM samples show different microstructures within the SLM fabricated structures as shown by the micrographs. In the SLM fabricated specimen (see figure on left side) an oriented microstructure with elongated grains occurs. Elongation takes place in building direction (indicated by white arrow) and is the result of heat transfer processes. The optical micrograph of the support structure is shown in the right figure. The supporting material is located between sample volume and building platform and has a much smaller volume than the sample. This is associated with better heat conductance and results in the granular microstructure visible in the picture [4].



CONCLUSION AND ACKNOWLEDGEMENT

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.

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