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Using Selective Laser Melting to Fabricate Anisotropic NiTi Implants

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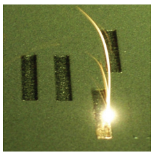
INTRODUCTION

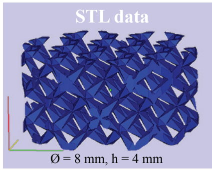


NiTi, a biocompatible and FDA-approved material[1], is a promising candidate for load-bearing implants as it combines low stiffness with high strength. Furthermore, it exhibits properties including pseudo-elasticity, shape memory effects and high damping capacities, which are based on a martensitic phase transition between a high- and a low temperature crystalline phase. The laser-based additive manufacturing method of selective laser melting (SLM) allows the fabrication of complex shaped NiTi-constructions with open pores or filigree lattice structures[2] with struts as thin as 200 µm. In this SLM-based study we show that gradients in phase transition temperature and mechanical properties can be induced in NiTi entities. In this way, bone implants with nature-analogue anisotropic properties shall be manufactured.

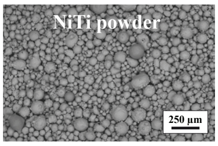
SAMPLE FABRICATION BY SLM

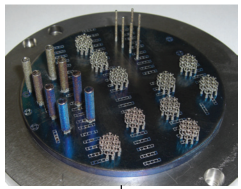
NiTi specimens were produced from pre-alloyed NiTi powder (Memry GmbH, Weil am Rhein) by the SLM Realizer 100 (SLM-Solutions, Lübeck, Germany). For the fabrication of scaffold structures and cylinders, laser power and scanning velocity were varied resulting in different overall energy inputs[3] as shown below. In addition, NiTi cylinders were created, which consist of several regions built with distinct process parameters.

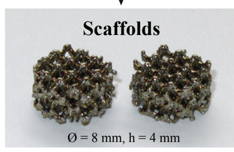
Energy density [J/mm^3]	60	70	84	100	130
Laser power [W]	62	72	76	80	95
Scanning velocity [mm/s]	71	171	150	133	122



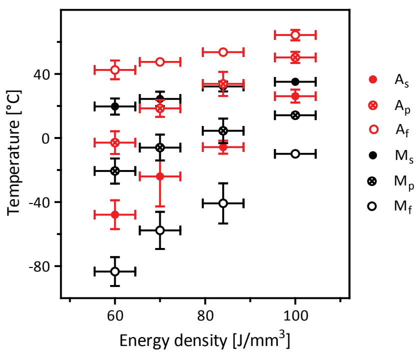
Processing parameters

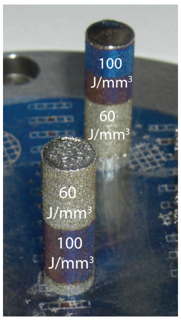






GRADUAL TRANSITION TEMPERATURES IN SOLIDS

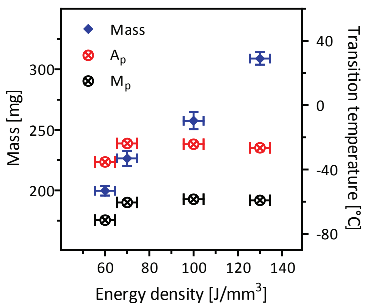


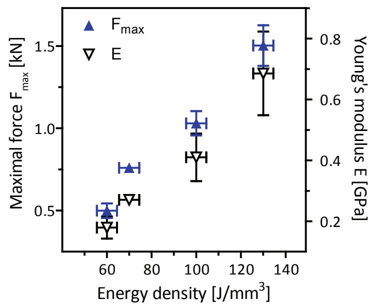


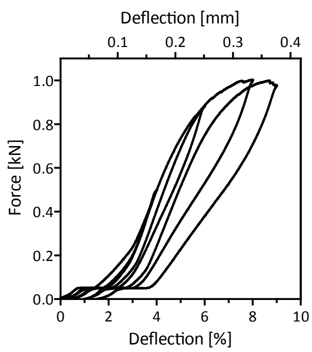
ΔT [K]	ΔA_s	ΔA_p	ΔA_f	ΔM_s	ΔM_p	ΔM_f
100 / 60 [J/mm^3]	29±6	35±3	20±6	12±6	17±3	48±6
60 / 100 [J/mm^3]	13±3	13±1	14±3	14±3	15±1	8±3

In dense SLM NiTi parts, the phase transition temperature can be adjusted by variation of the overall energy input during processing. By applying different sets of processing parameters in single parts, gradients in the transition temperatures can be induced. This allows a local modification and gradual changing of thermo-mechanic properties. In this way NiTi implants with anisotropic properties can be manufactured.

PROPERTIES OF SLM NITI SCAFFOLDS







In scaffolds, the variation of the energy density does not lead to altered phase transition temperatures. Still, the scaffold masses increase due to thickening of the laser paths with increasing energy input[4]. This leads to thicker scaffold struts and to an increase in the failure forces during compression testing. Because of the increasing strut thickness, also the scaffolds young's moduli increase with energy density. The scaffolds show the characteristic pseudoelastic behaviour (see graph at the left), they recover a deflection of up to 7%.

CONCLUSION & ACKNOWLEDGEMENT

The mechanical properties of scaffolds and the phase transition temperatures in dense cylinders were adjusted by the process parameters during the SLM fabrication. This approach allows a local modification of properties in SLM NiTi-structures just by varying the process parameters. In this way, gradients, either in mechanical properties or in the phase transformation can be induced. Such gradients permit the fabrication of nature-analogue anisotropic nanostructures. Tailoring structural and related mechanical properties of NiTi-scaffolds, we aim to create bone implants with an enhanced osseoinductive performance. This should be realized by implants which conduct motions for a mechanical tissue stimulation.

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References: [1] ASTM International, F 2063-05. [2] Bormann T. et al. (2011), eCM 22: 12. [3] Bormann T. et al. (2010), Proc SPIE 7804: 78041. [4] Yadroitsev I. et al. (2010), J Mater Process Technol 210(12): 1624-1631.