Selective laser melting of NiTi alloys

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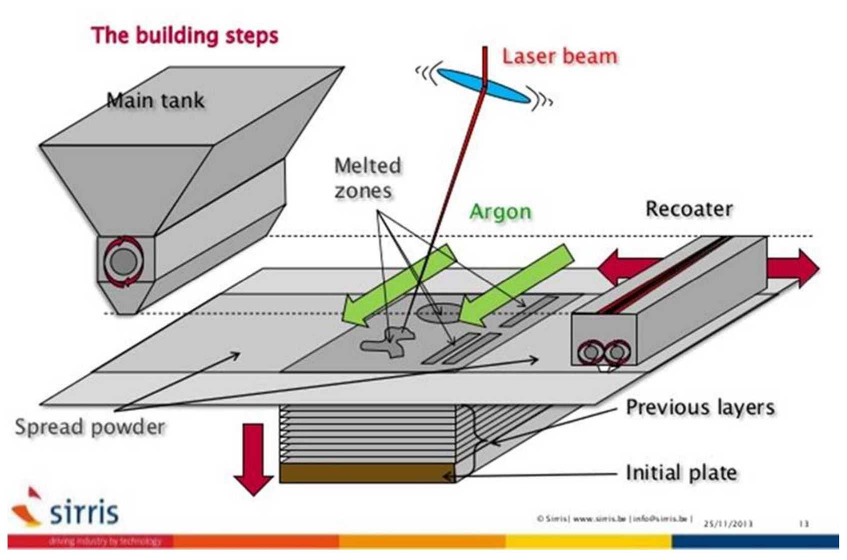
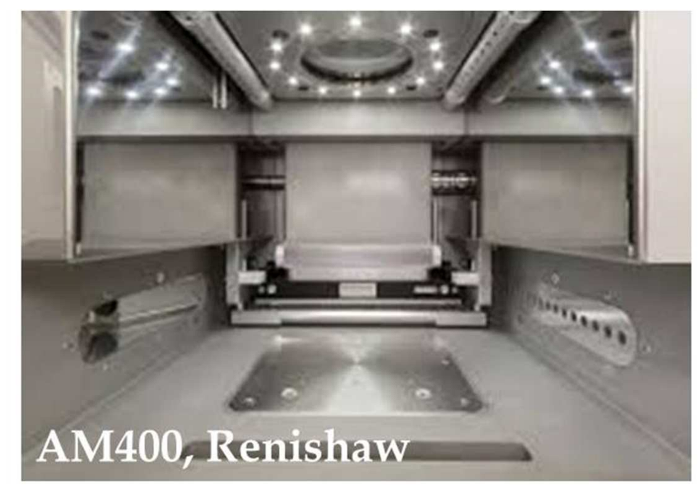
THE SLM PROCESS



Selective laser melting (SLM) is an additive production process that uses a laser beam source to selectively melt metal micrometric powder, layer by layer and following a 3D CAD model. It allows producing three-dimensional objects of complex geometry, limiting the use of tools and overcoming the problems related to traditional production technologies. As a first consequence, the possibility to produce near-net-shape components has expanded the field of applications of NiTi.

source	laser beam, 200-400W (1kW), CP&PW
scans	~20m/s, spot 60-100micron
production	1-20cm^3/h
volume	250x250x300 mm^3 standard, 800x400x500 mm^3
Working conditions	Room temperature and pressure, Ar or N_2 flux intake, O_2<0,1%
powder	5-45micron (Gaussian)
layer	20-100micron

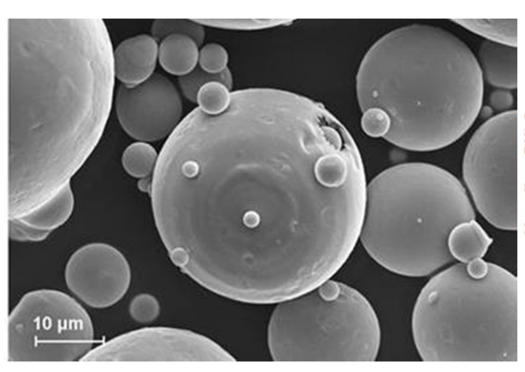


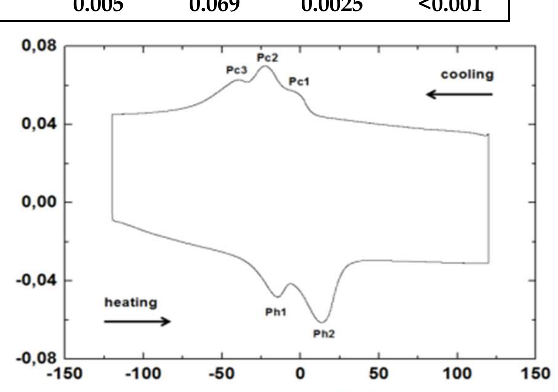
OBJECTIVE In this work, an optimized set of SLM process parameters was selected to deepen the variation of the microstructure, the phase transformation temperatures and the mechanical response of NiTi parts fabricated by SLM, starting from a NiTi powder with 55.2wt% Ni.

METHODS The **NiTi powder** is produced via gas atomization with a mean particle size below 45µm. The powder was purchased from TLS Technik GmbH & Co. Spezialpulver KG (Bitterfeld, Germany). NiTi samples were produced by a Renishaw AM400 SLM machine. Prior to processing, oxygen level is take lower than 500 ppm and the working chamber is filled with Argon. No preheating was applied to the platform.

The NiTi powder

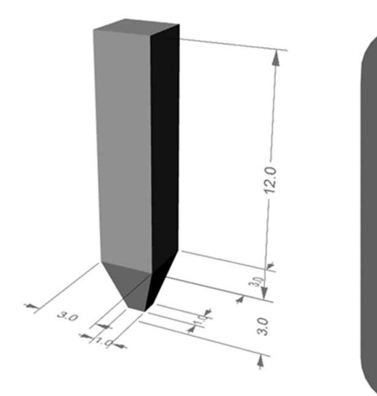
Ti [wt.%]	Ni [wt.%]	C [wt.%]	O [wt.%]	N [wt.%]	H [wt.%]
bal	55.2	0.005	0.069	0.0025	<0.001

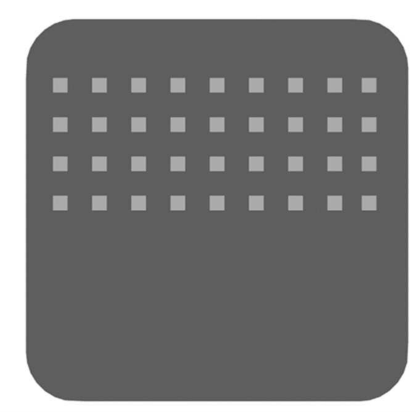




cooling						heating				
Ms [°C]	P_c1 [°C]	P_c2 [°C]	Pc3 [°C]	Mf [°C]	ΔH_c [J/g]	As [°C]	P_h1 [°C]	P_h2 [°C]	Af [°C]	ΔH_h [J/g]
10	-5	-22.3	-39.2	-68.5	15.3	-34.5	-14.7	13.4	28.2	15.4

The laser power **P**, the laser point distance *d* and the layer thickness ***l*** were kept constant at 250 W, 60 µm and 30 µm respectively. Besides, three laser exposure times were chosen: 60, 48 and 40 µs. Therefore, the laser speed *v*, calculated as the ratio between the laser exposure distance *d* and the laser exposure time *t*, was 1000, 1250, 1500 mm/s. Moreover, four hatching distance ***h*** values were selected: 50, 75, 100, and 120 µm. Consequently, the first job is made up of twelve families (named from F1 to F12), composed by three samples each.

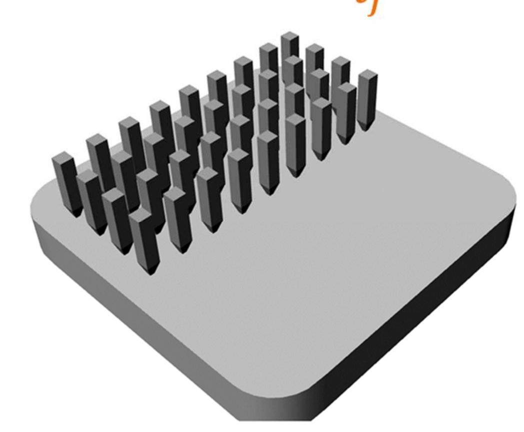




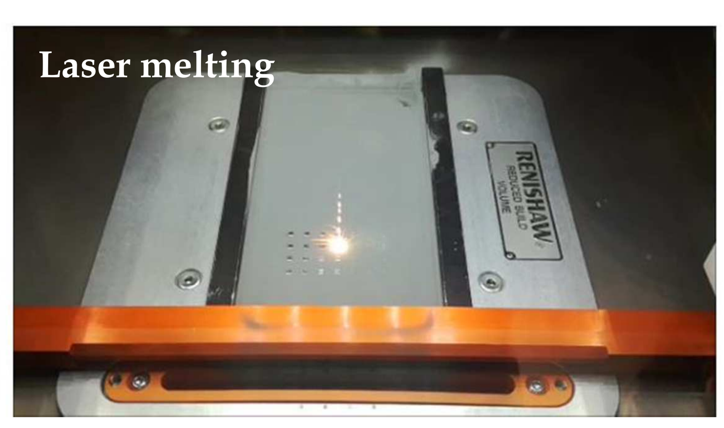
The NiTi CAD

LASER ENERGY DENSITY

$$E_{i,j} = \frac{P}{v_j \cdot l \cdot h_i} = \frac{P}{\frac{d_j}{t_j} \cdot l \cdot h_i}$$



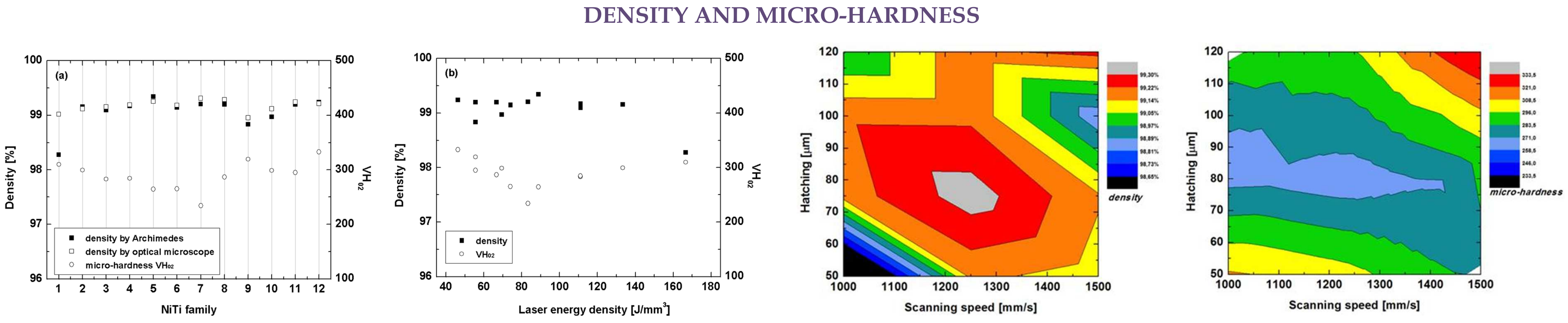
RESULTS



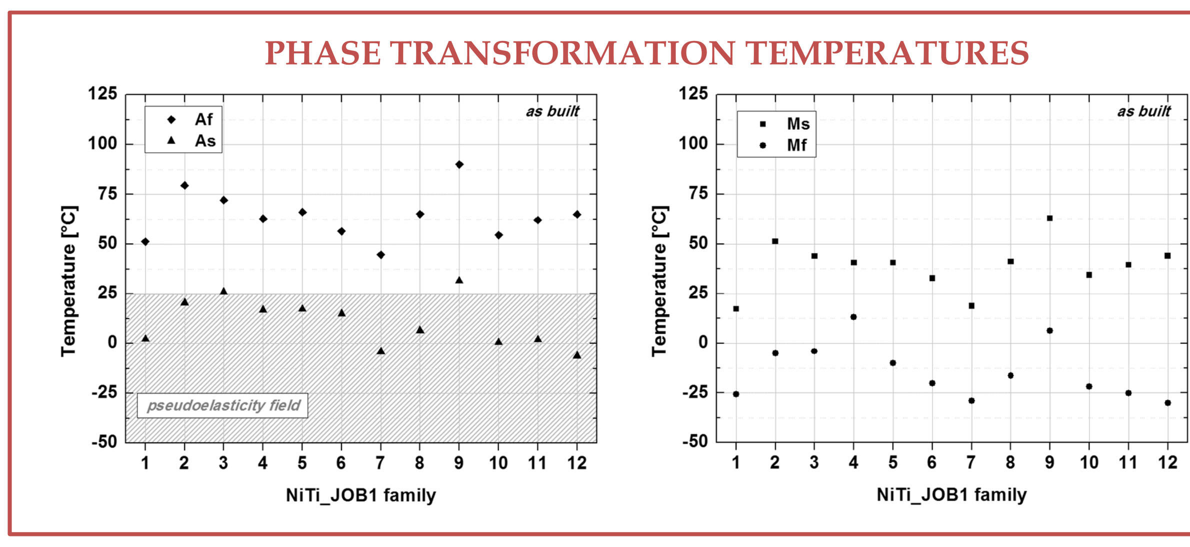
The NiTi JOB

Near **fully dense** NiTi specimens have been obtained. Furthermore, the Af of the SLM products is higher than the powder independently from the process parameters. According to **DSC data**, it was found that Af varies from 45 to 90 °C while Mf changes in the [-25; -13] °C temperature range. This may be ascribed to the evaporation of Ni during the process. This is confirmed by EDX analysis; as examples, Ni content of F2 and F3 families was 49.55 at% (0.32 st. dev.) and 50.06 at% (0.006 st. dev.), respectively.

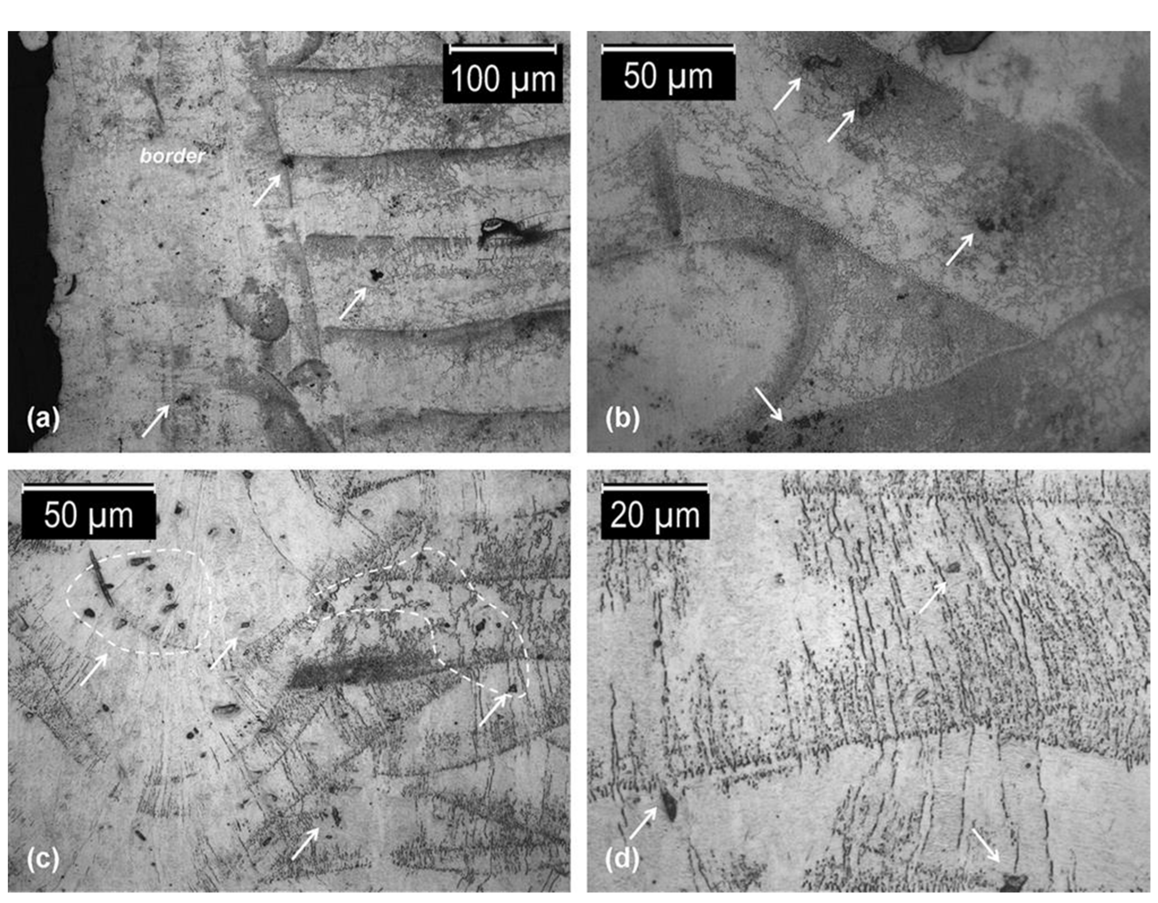
DENSITY AND MICRO-HARDNESS

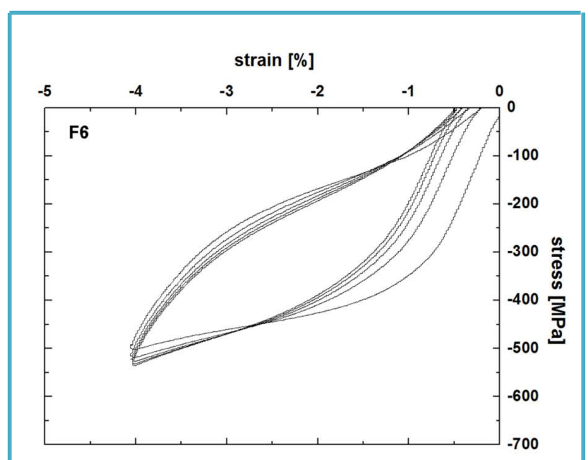


PHASE TRANSFORMATION TEMPERATURES



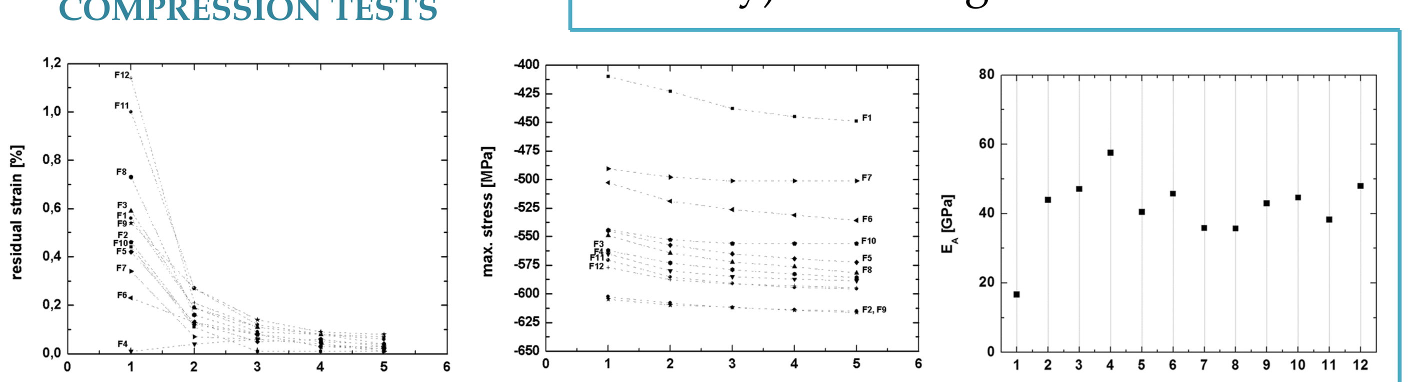
However, precipitates formation may also contribute in some extent to this effect. Precipitates have been found in all the families. The formation of precipitates is thought to be principally enhanced by the pulsed laser energy source which generates discrete melt pools and subsequently increases the number of regions where aging occurs. Additionally, this effect is more pronounced for lower *h* values for which the band of overlaying of consecutive laser tracks is larger.

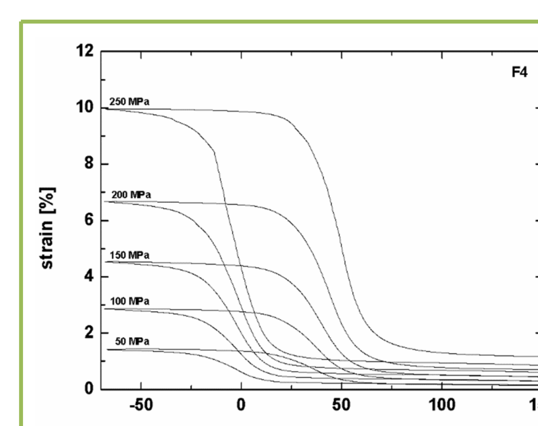




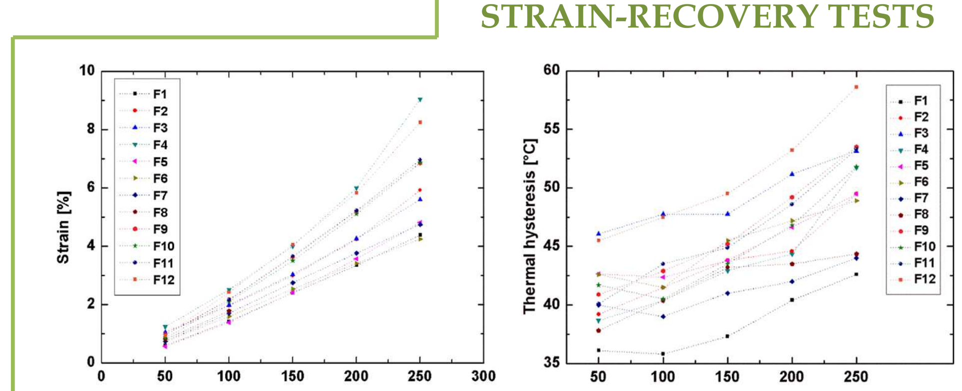
In the austenite field, compression tests show stable flag shaped curves. Besides, high strain recoveries at different stress levels and low residual strains have also been registered. In this regard, the choice of *h* = 75 µm and *t* = 60 µs (F4 family) produces promising shape memory performance. Furthermore, in both the mechanical studies (compression and strain recovery tests) as well as density measurements, the choice of *h* = 50 µm and *t* = 60 µs (which correspond to F1 family) has brought the worst outcomes.

COMPRESSION TESTS





STRAIN-RECOVERY TESTS



CONCLUSIONS Ni-rich NiTi powder was used to fabricate NiTi components by selective laser melting. The loss of Ni during the process, primarily due to evaporation and precipitates formation, leads to a depletion of Ni in the NiTi matrix and a consequent increasing of phase transformation temperatures of the as-build parts. The hatching distance and the exposure time resulted to be more effective than the laser energy density in determine the pseudoelastic and the shape memory responses. Repeatability of results as well as thermal homogeneity of NiTi as-build samples are two key challenging goals for next studies.

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