info@csem.ch www.csem.ch

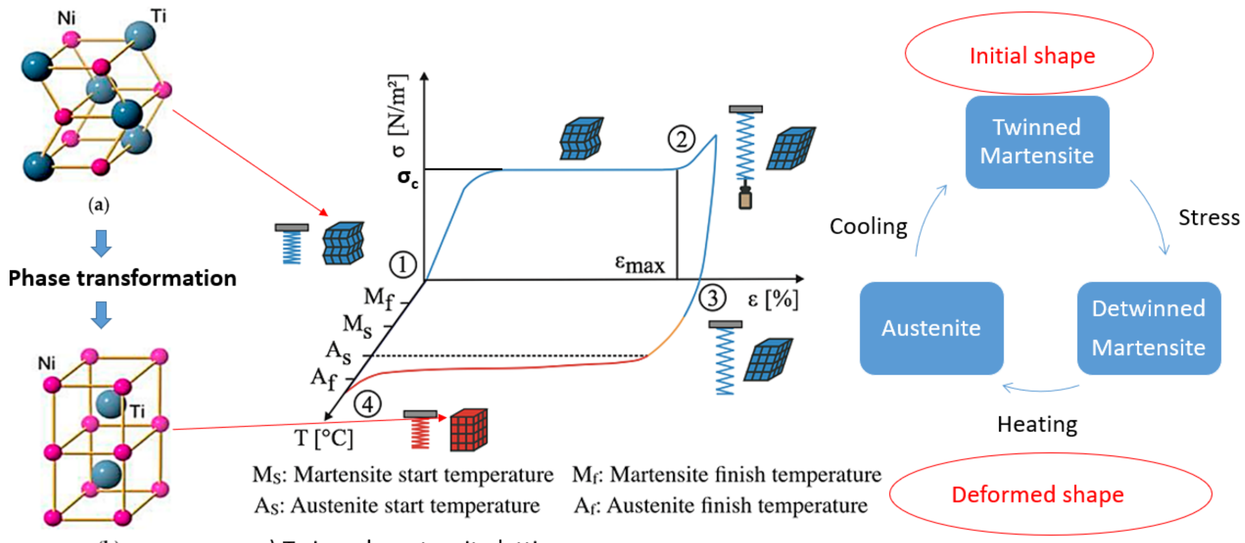
Additive Manufacturing of $Ni_{0.494}Ti_{0.506}$ Shape Memory Alloy

L.Bonsack, O.Sereda, V.Pejchal, M.Dadras,

Additive manufacturing and component reliability, CSEM, Neuchâtel, Switzerland

Introduction

Selective laser melting process has been used to fabricate shape memory alloy (SMA) Nitinol. This alloy is difficult to machine due to the stress induced martensite-austenite phase transformation (responsible for the shape memory effect). It has been shown that 3D printing is an enabling technology that allows to print near-net shape structures from poorly machinable materials. This study focuses on the influence of SLM process on the matrix nickel content which strongly influences the transition temperature.

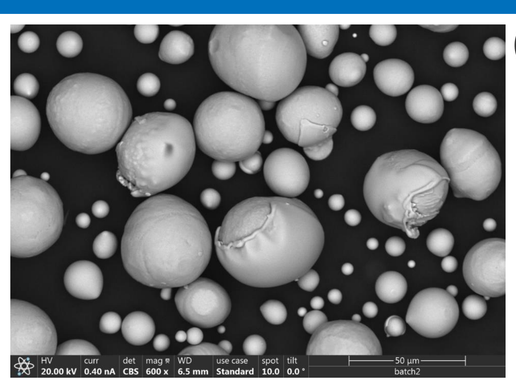


(IMT), I. (2019). *KIT - IMT - Research Groups - Kohl - Shape Memory Effect*. [online] Imt.kit.edu. Available at: https://www.imt.kit.edu/889.php#gallery-1 [Accessed 29 Oct. 2019]. (shape memory effect scheme)
Chekotu, J., Groarke, R., O'Toole, K. and Brabazon, D. (2019). *Advances in Selective Laser Melting of Nitinol Shape Memory Alloy Part Production*. (martensitic and austenitic lattice)

Objectives

Develop the process for manufacturing of NiTi alloy by SLM process considering part density >99%, exhibiting shape memory effect at room temperature.

Results & discussion powder ($Ni_{0.494}Ti_{0.506}$)

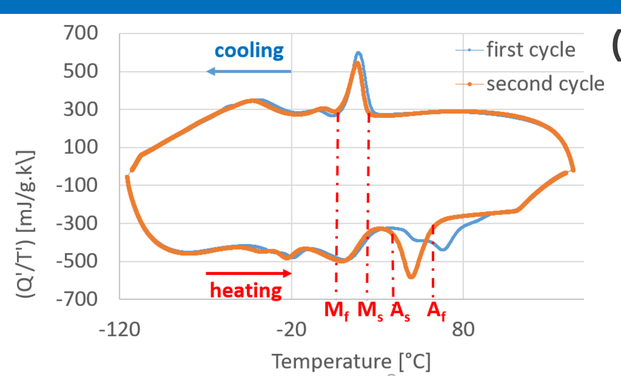


(a)

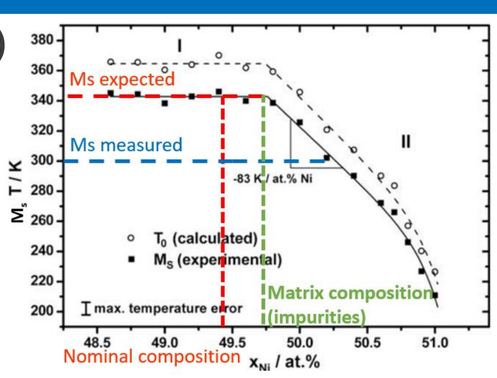
Measurement technique	Ni
ICP-EOS	**49.3** ± 2.2 at%
EDX	**49.3** ± 0.4 at%
Supplier specifications	**49.4** at%

(b)

	O	C
Measured	782 ppm	33 ppm
Supplier specifications	607 ppm	60 ppm



(c)

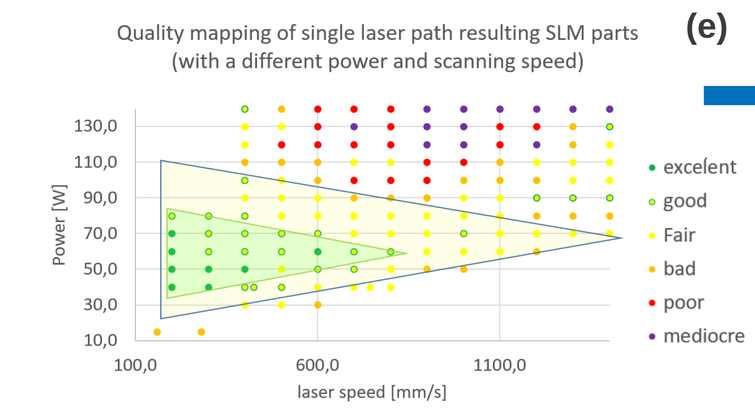


(d)

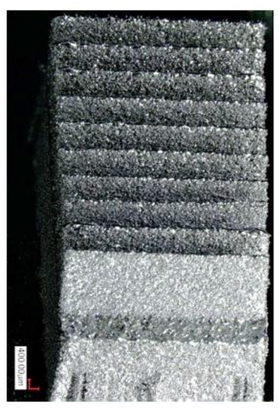
C. Haberland, M. Elahinia, J. M. Walker, H. Meier, and J. Frenzel, "On the development of high quality NiTi shape memory and pseudoelastic parts by additive manufacturing," *Smart Mater. Struct.*, vol. 23, no. 10, 2014, doi: 10.1088/0964-1726/23/10/104002.

Powder have a near spherical shape (a), nickel content measured to be 49.3 at% (b). Ms should be 340K (d) but it is measured to be 300K (c). As impurities are Ti consuming, if taking into account O and C content, the matrix composition would be 49,67 at%. Thus, impurities do not explain this Ms shift (region I) where Ms is independent of Ni content) .

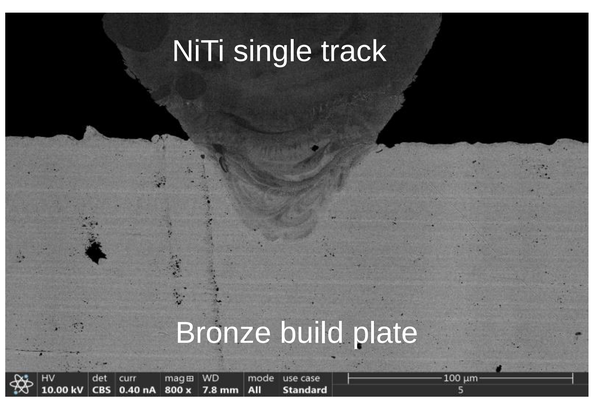
Results & discussion SLM parts



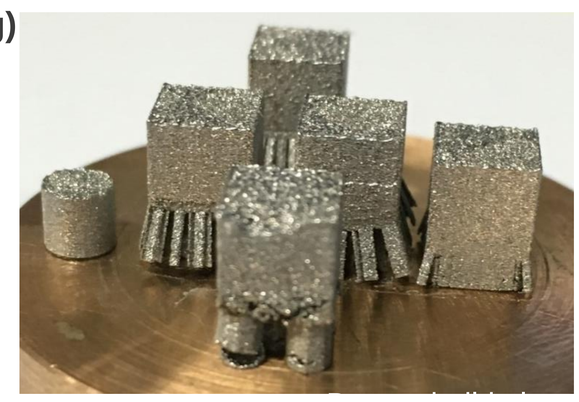
(e)



(f)

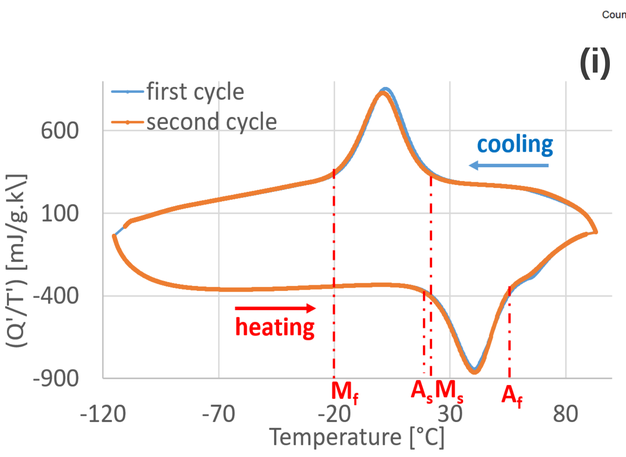


(g)

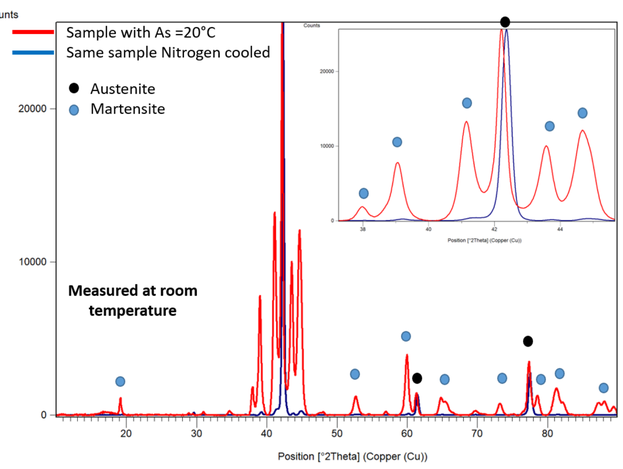


(h)

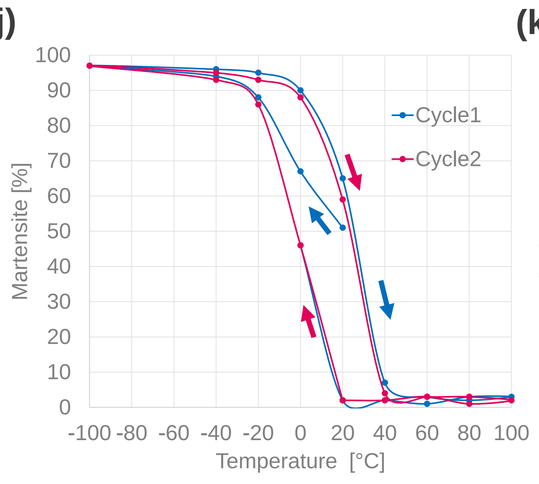
SLM operational window has been determined through single tracks (f) fabrication (green triangle) (e). Bronze build plate material has been found to be suitable material to print test cubes (g-h). Dedicated supports design has been used to avoid part delamination. The hatch distance between 2 laser tracks has been optimized to process bulk parts ➔ 99,8% relative density.



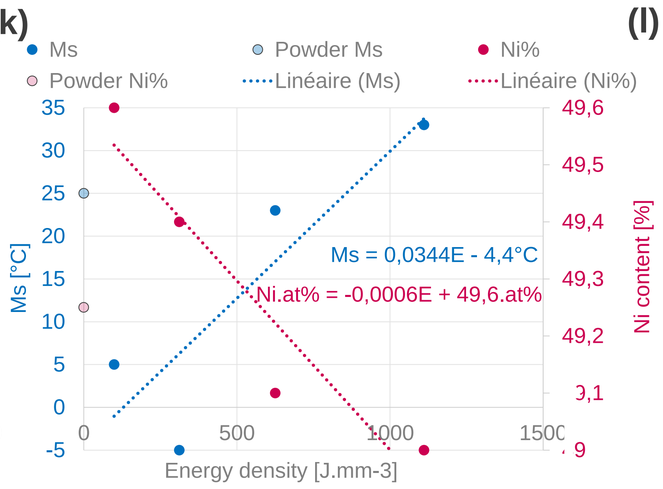
(i)



(j)



(k)



(l)

Austenite to martensite phase transformation (responsible for shape memory effect) confirmed after SLM process (cryo-DSC (i) and cryo-XRD (j-k)). After being cooled in nitrogen, the sample is composed of 86% martensite at room temperature. There is Ni content depletion as process energy density increases (evaporation during process) which leads to increase in Ms (l).

Conclusion

SLM permits to fabricate dense SMA parts having an As=20°C and 99,8% relative density (printed spring). Ms increases with laser power energy density because Ni evaporates more than Ti is consumed by impurities. Leading to an overall Ni content matrix depletion, inducing a Ms increasing with energy density. The transformation temperate As near 20°C shows that one-way shape memory effect is possible at room temperature with the used feedstock powder.

Printed NiTi spring cooled in nitrogen and deformed at room temperature

Heated