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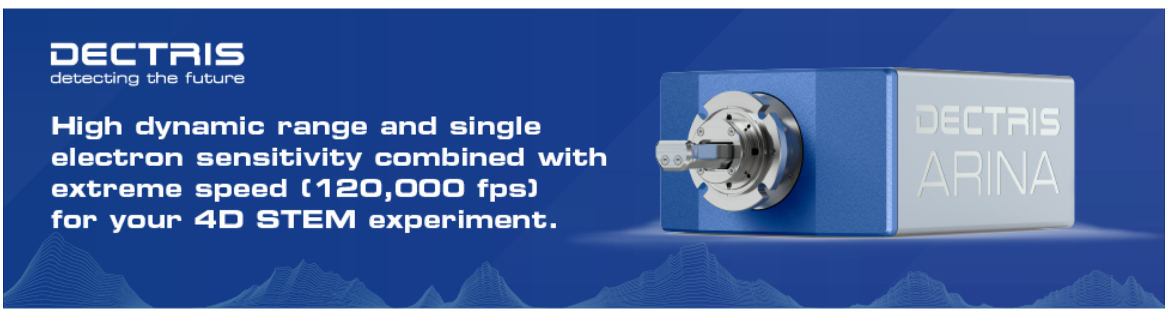

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Study of Phase-transformation Behavior in Additive Manufacturing of Nitinol Shape Memory Alloys by In Situ TEM Heating

Yi-Chieh Yang[1], Jia-Ning Zhu[2], Thor Bjerregård Sneppen[3], Alice Bastos da Silva Fanta[1], Vera Popovich[2], and Joerg R. Jinschek[1],*

[1]*National Center for Nano Fabrication and Characterization (DTU Nanolab), Technical University of Denmark (DTU), Kgs. Lyngby, Denmark*
[2]*Department of Materials Science and Engineering, Delft University of Technology, Delft, The Netherlands*
[3]*Department of Mechanical Engineering, Technical University of Denmark (DTU), Kgs. Lyngby, Denmark*

*Corresponding author: jojin@dtu.dk

Shape memory alloys (SMAs) [1, 2] are gaining attention in many applications, such as in actuators [3], sensors [4], and dampers [5], due to their attractive property of shape memory effects (SME). SME is a capability of SMAs to regain the original shape of a deformed material upon heating through the reversible martensitic transformation. According to the stress-strain curve for the SMAs, the applied strain and the working temperature are used to determine the stress of the SMA and its phase. For optimizing the working properties of SMA, the corresponding phase transformation temperature is an essential parameter, and it strongly depends on local microstructure characteristics, such as chemical composition [6], precipitates [6, 7], dislocations [8] and grain size [9]. As a result, an in-depth understanding of the correlation between the structural variation and the applied temperature is essential for optimizing fabrication parameters to control the application conditions.

Here, NiTi (Nitinol) SMA is used to fabricate a sample using laser powder bed fusion (L-PBF), a metal additive manufacturing technique [10, 11]. The ability to build parts with complex geometries [12] and *in situ* tailorable microstructures [13] makes L-PBF a great choice for fabrication. However, since laser rastering in L-PBF introduces an inhomogeneous heating profile, in each scanning point a melt pool with non-uniform composition distribution perpendicular to the build direction is introduced which results in metastable phases within in the melt pool, and thereby influencing the structural and shape memory effect stability.

In order to capture the correlation between phase transformation and the local inhomogeneity, *in situ* heating experiments in transmission electron microscopy (TEM) are used to study the SME in L-PBF Nitinol SMAs. To study the variation in phases with increasing temperature, TEM samples from different areas of the melt pool were prepared by focused ion beam (FIB) and placed on the MEMS-based microheaters for in-situ TEM heating experiments.

Observing the phase transition upon *in situ* heating in L-PBF Nitinol SMAs shows a higher phase transformation resistance in the melt pool boundaries, due to the fine cellular structure and high-density dislocations. Further segregation at the grain boundaries also causes the change in the phase transition temperature. Our results indicate the capability to apply in-situ TEM heating experiments to study microstructural transformations and providing essential insights to further optimize process parameters in (additive) manufacturing, such as controlling the functional anisotropy [14].

References

1. K Otsuka and X Ren, *Prog Mater Sci*, **50** (2005), p. 511. doi:10.1016/j.pmatsci.2004.10.001
2. T Kurita *et al.*, *J Mater Sci*, **39** (2004), p. 4391. doi:10.1023/B:JMSC.0000033435.24088.2c
3. JJ Epps and I Chopra. *Smart Mater Struct*, **10** (2001), p. 104. doi:10.1088/0964-1726/10/1/310
4. JM Jani *et al. Mater Des*, **56** (2014), p. 1078. doi:10.1016/j.matdes.2013.11.084
5. S Saadat *et al.*, *Smart Mater Struct*, **11** (2002), p. 218. doi:10.1088/0964-1726/11/2/305
6. J Frenzel *et al.*, *Acta Mater*, **58** (2010), p. 3444. doi:10.1016/j.actamat.2010.02.019
7. J. Khalil Allafi *et al.*, *A. J Phys IV*, **11** (2001), p. 529. doi: 10.1051/jp4:2003974
8. GF Eggeler *et al.*, *Mater Sci Forum*, **327** (2000), p. 183. doi:10.4028/www.scientific.net/MSF.327-328.183
9. T Waitz *et al.*, *J Mech Phys Solids*, **55** (2007), p. 419. doi:10.1016/j.jmps.2006.06.006
10. J-N Zhu *et al.*, *Additive Manufacturing*, **38** (2021), 101802. doi:10.1016/j.addma.2020.101802
11. A Dehghanghadikolaei *et al.*, *J Mater Sci*, **54** (2019), p. 7333. doi:10.1007/s10853-019-03375-1
12. M Speirs *et al.*, *Journal of the Mechanical Behavior of Biomedical Materials*, **70** (2017), p. 53. doi:10.1016/j.jmbbm.2017.01.016
13. X Wang *et al.*, *Scripta Mater*, **146** (2018), p. 246. doi:10.1016/j.scriptamat.2017.11.047
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