Joint PhD subject

Title :

"Microstructure-Property Relationships in Titanium and Nickel-Titanium Based Alloys Additively Manufactured"

Hosting laboratories :

Institut de Recherche Dupuy de Lôme
(IRDL UMR CNRS 6027)

and

Institute of Physics of the Academy
of Sciences of the Czech Republic (Prague)

Supervisors :

Shabnam ARBAB CHIRANI
IRDL (UMR CNRS 6027) / ENSTA Bretagne – shabnam.arbab@ensta-bretagne.fr

Luc SAINT-SULPICE
IRDL (UMR CNRS 6027) / ENIB – sulpice@enib.fr

Ludek HELLER
Institute of Physics of the Academy of Sciences of the Czech Republic – heller@fzu.cz

Starting period : fall 2024

Salary : ~2,200 €/month (net)

Profile : Master of Science in materials science, mechanics of materials or mechanical engineering. A solid backgroundin metallurgy and material behavior modeling is particularly appreciated. A good level in English is required.

Applications : Detailed CV, cover letter, detailed exam results, master's notes, names and contact details of professors and supervisors who have followed your work, letters of recommendation, master's thesis, journal and conference articles or any other document establishing your skills for this doctorate. Contact : Shabnam Arbab Chirani shabnam.arbab@ensta-bretagne.fr. Deadline : October 30 2024.

Keywords : plasticity, martensitic phase transformation, additive manufacturing, microstructure, self-heating, multi-scale modeling, thermomechanical testing

Context

The two research teams have been collaborating since 2014. The team from Prague is more specialized in metallurgy, microstructure, and thermomechanical properties characterization , while the IRDL focuses on studying and modeling material behavior and fatigue.

Background and subject

Components from Ti- or NiTi-based alloys, widely used in applications such as biomedical implants, actuators, and aerospace systems, are highly valued for their functional properties such as shape memory and superelasticity [1, 2]. These unique properties are, however, critically affected by the microstructure properties such as texture, and internal stresses. The latter inevitably arises from Additive Manufacturing (AM) being nowadays used to fabricate customized or complex shaped components. The internal stresses and texture directly affect their thermomechanical functional behavior, including fatigue performance [3]. Since the functional behaviors of Shape Memory Alloys (SMA) are due to the recoverable deformation processes derived from martensitic transformation, which are associated with lattice distortion and rotation of crystal lattice, textures in austenite and martensite phases evolve during thermomechanical loads. Besides recoverable strains, SMAs undergo plastic deformation. It is due to the combination of recoverable transformation and irrecoverable plastic strains, that internal stresses are easily introduced into SMAs by mechanical deformations. The AM processing results in generation microstructure, textures and internal stresses in fabricated components, which are different from those known in cast alloys. The AM processing can thus be also used to tailor the microstructure in order to achieve thermomechanical properties not achievable by standard technological routes.

The goal of the proposed PhD program is to explore the design space of AM processing and subsequent themomechanical processes in order to find their parameters providing Ti- or NiTi-based components with optimized microstructures, textures and internal stresses. For instance, microstructures with textures not achievable by conventional processing methods that inhibit easy slip systems in austenite and martensite will be targeted. Moreover, AM will focus on microstructures with stronger texture index compared to conventional methods in order to amplify their effects on functional and fatigue behavior.

Secondly, strategies towards intentional texture and phase gradients from surface to the core will be addressed. The aim will be to provide surface with larger transformation strains or complaint martensitic phase structure thus relieving surface from excessive stresses and preventing cracks initiation.

Finally, rapid characterization techniques are essential for efficiently evaluating and optimizing the fatigue and functional properties of AM-fabricated NiTi components. One promising approach is the use of self-heating methods, which enable a rapid assessment of fatigue behavior by correlating the thermal response of the material under cyclic loading with its mechanical degradation [4]. This technique allows for the accelerated determination of fatigue limits and the identification of fatigueprone regions in the material. By leveraging self-heating measurements, the fatigue performance of different AM-fabricated SMA microstructures and textures can be rapidly screened, facilitating faster feedback loops in the optimization process. The integration of self-heating methods will thus serve as a complementary tool in achieving the desired functional and fatigue properties in SMA components fabricated through AM.

References

[1] G. Zhang, H. Wang, Z. Li, B. Yang, H. Yan, and L. Zuo. “Giant Elastocaloric Effect Covering a Wide Temperature Region in a Directionally Solidified Ni50Mn30Ti20 Alloy.” *Scripta Materialia* 237 (December 1, 2023): 115725. 10.1016/j.scriptamat.2023.115725

[2] S. Li, W.-T. Lee, J.-T. Yeom, J. G. Kim, J. S. Oh, T. Lee, Y. Liu, and T.-H. Nam. “Towards Bone-like Elastic Modulus in TiNbSn Alloys with Large Recovery Strain for Biomedical Applications.” *Journal of Alloys and Compounds* 925 (December 5, 2022): 166724. 10.1016/j.jallcom.2022.166724

[3] C. Chluba, W. Ge, R. Lima de Miranda, J. Strobel, L. Kienle, E. Quandt, and M. Wuttig. “Ultralow-Fatigue Shape Memory Alloy Films.” *Science* 348, no. 6238 (May 29, 2015): 1004–7. 10.1126/science.1261164

[4] T. Cullaz, L. Saint-Sulpice, M. Elahinia, and S. Arbab Chirani. “Self-Heating and Fatigue Assessment of Laser Powder Bed Fusion NiTi Alloy with High Cycle Fatigue Mechanisms Identification.” *Metals* 14, no. 5 (May 2024): 496. 10.3390/met14050496