Modelling of hydrogen effects on the thermomechanical behaviour of NiTi-based shape memory alloys

***T. Ben Zineb**,** N. Ulff[ς], C. Bouby[+], A. Lachiguer[&], T. Bouraoui[η]

[*] LEM3, CNRS UMR 7239, Université de Lorraine, Vandoeuvre-lès-Nancy, 2 rue Jean Lamour, 54500, France.
Email: tarak.ben-zineb@univ-lorraine.fr

[ς] LEM3, CNRS UMR 7239, Université de Lorraine, Vandoeuvre-lès-Nancy, 2 rue Jean Lamour, 54500, France.
Email: nicolas.ulff@univ-lorraine.fr

[+] LEM3, CNRS UMR 7239, Université de Lorraine, Vandoeuvre-lès-Nancy, 2 rue Jean Lamour, 54500, France.
Email: celine.bouby@univ-lorraine.fr

[&] LGM, ENIM, Université de Monastir, Monastir, Av. Ibn ElJazzar, 5019, Tunisia.
Email: lachigueramani@yahoo.fr

[η] LGM, ENIM, Université de Monastir, Monastir, Av. Ibn ElJazzar, 5019, Tunisia.
Email: tarak.bouraoui@gmail.com

NiTi Shape Memory Alloys (SMAs) exhibit a reverse martensitic transformation from martensite to austenite. It induces a recovery deformation at constant force widely considered for orthodontic treatments despite some fractures observed after few months in buccal cavity. A degradation of the mechanical properties of NiTi arches appears due to the presence of hydrogen. Accounting for effects of hydrogen diffusion on the NiTi SMA behaviour a coupled chemo-thermo-mechanical constitutive model needs to be formulated. Based on a work of Lachiguer et al. (2016), a first step consists in introducing material parameters dependences (transformations temperatures and maximum strain) to the normalized concentration of hydrogen in the NiTi constitutive law developed by Chemisky et al. (2011). Based on experimental results, it allows to formulate a first hydrogen dependant SMA behaviour model.
The main limitation of this model is that the hydrogen concentration can only be considered as homogeneous. As nano-indentation tests reveal a heterogeneous distribution, it becomes necessary to take into account the gradient of hydrogen distribution from the surface to the cross section center.
To this end, we have to write equilibrium equations for each field (thermal, mechanical and chemical fields). These equations are then discretized to be solved numerically by finite element method. A special finite element with coupled degrees of freedom (displacements, temperature, hydrogen concentration) is developed and implemented in the Abaqus finite element software through the UEL subroutine. The obtained numerical tool will allow to analyze the effect of hydrogen diffusion on the performance of SMA-based orthodontic arches.

Keywords: NiTi Shape Memory Alloy, Hydrogen diffusion, Finite elements, Constitutive models, Orthodontic applications