Phd position 2024- CEMEF

TITLE	Characterization and modeling of the Bauschinger effect relaxation, recovery, and mechanical behavior of a martensitic steel
Project acronym	CAMERAM
Global objective of work	The objective is to model the evolution of mechanical properties of quenched & tempered martensitic pipes during a finishing operation consisting in a small plastic deformation followed by a stress-relief annealing. This evolution, induced by microstructure evolution, is due to fine plasticity mechanisms during deformation (isotropic and kinematical work-hardening) and, during annealing, static recovery and Bauschinger effect relaxation. The PhD student will : • Conduct an experimental campaign at laboratory scale, of heat treatment and mechanical tests under cyclic conditions, • Select the mechanical constitutive law and recovery models suited to these materials [1,2,3], and identify their parameters on the basis of experimental data, • Implement these models in the Finite Element software Forge® in view of a predictive simulation chaining deformation and annealing, • Using this knowledge and tools, define suitable conditions of heat treatment, carry it out in real size, perform mechanical testing on samples machined from these pipes and compare model predictions to measurements.  Figure 1 : An example of threaded pipe joining
Context	**Vallourec** is one of the leading producers of steel pipes and the world leader for the development of "premium", high tightness threaded connections between

pipes. Such connections are used in many industries, like fossil (oil / natural gas) or « green » (geothermal) energy exploitation. Presently, **Vallourec** investigates other applications such as CO_2 capture & storage in geological strata or former oil/gas pits. The use for H_2 storage pits is also under study. The extreme working conditions of these structures (up to 3000 Tons in tension / compression, 200 MPa internal/external pressure, temperatures from ambient to 250°C) impose stringent specifications which render their development complex.

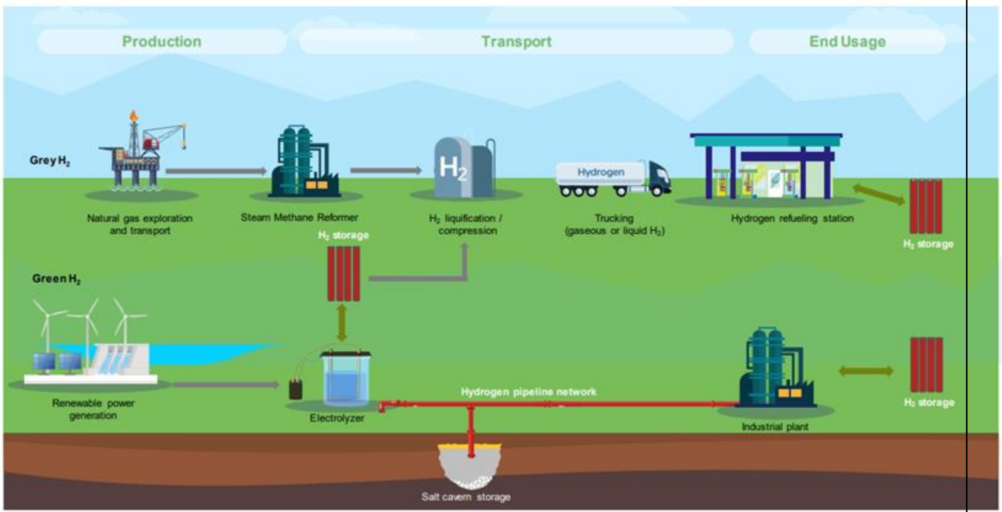

Figure 2: Chain value of hydrogen as an energy vector

The industrial problem tackled in this PhD work mainly deals with premium integral connections, machined at both ends of martensitic, high yield strength (YS) steel pipe, previously cold-strained then "stress-relieved" through an induction heat treatment.

The pipe end plastic straining operation (expansion / shrinkage) modifies mechanical characteristics, activating in particular the Bauschinger effect (figure 2): after a compressive deformation, a following tension test shows a significantly lower apparent yield strength. This suggests that local plastic strain may occur for a stress level well below the specification YS for the in-service pipe. To reverse this phenomenon, a stress-relief annealing heat treatment is performed on the deformed zone exclusively, activating static recovery and relaxation. It is supposed to bring martensite back to a metallurgical state with mechanical properties identical, to a certain tolerance, to those before plastic strain. This shall ensure homogeneity of the mechanical properties over the whole pipe.

Temperature and time of this thermal treatment must be optimized specifically for each single steel grade, in particular depending on its tempering temperature. To do so, this study conjugates experiments (heat treatment and mechanical testing, observations and microstructural analyses) and complex plasticity model identification (kinematical hardening, or even distorsional hardening) to describe the mechanical properties evolution both during deformation and during annealing.

The thus identified models, of strain hardening during martensite deformation, of recovery and relaxation during annealing, shall be implemented in the Finite Element software Forge NxT, jointly developed by CEMEF and Transvalor [6].

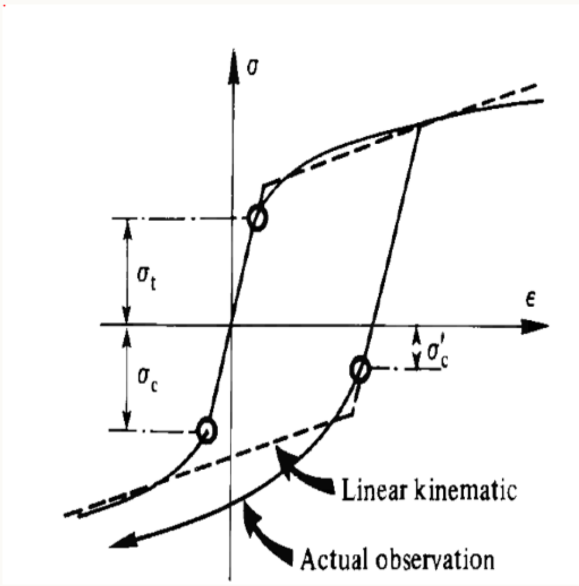

Figure 3 : the Bauschinger effect [4]

The main objective of the work is to predict precisely and efficiently the return to pre-deformation mechanical properties, as a function of annealing time and temperature. The prominent points will be :

- a bibliographic study on these high resistance steel physical and mechanical metallurgy, on martensite properties, together with different advanced models of work-hardening during cold forming [1,2] ;
- heat treatment experiments and mechanical tests under well-controlled laboratory conditions; to ensure the generality of the models to be developed, the Design of Experiments shall cover potential industrial conditions for at least two steel grades and two levels of pre-deformation (both in expansion and contraction);
- the choice of a work-hardening model and the development of a parameter identification methodology;
- microstructural analysis of activated mechanisms during heat treatments
- the choice of a static recovery model and the development of a parameter identification methodology
- their implementation in Forge as a « user-defined behaviour » ;
- the application to an experimental validation campaign on real pipes.

[1] Vicente Alvarez, M.A, Marchena, M., Perez, T. (2008). Recovery Kinetics of Cold-Deformed Cr-Mo Steels, Metall. Mater. Trans. A 39 (13) 3283–3290.DOI : 10.1007/s11661-008-9655-6

[2] Vicente-Alvarez, M.A., Bergant, M., Perez, T. (2010). Relaxation of the Bauschinger effect by thermal treatment on tempered martensitic steels, Materials Science and

Engineering: A, 527, 5939–5946. DOI: 10.1016/j.msea.2010.06.010.

[3] Barlat, F., Yoon, S.Y., Lee, S.Y., Wi, M.S., Kim, J.H. (2020). Distortional plasticity framework with application to advanced high strength steel, International Journal of Solids and Structures, 202, 947-962, DOI: 10.1016/j.ijsolstr.2020.05.014.

[4] Lemaitre, J., Chaboche, J.-L.. (1994). Mechanics of solid materials (Cambridge University Press)

[5] Kolpak, F., Hering, O., Tekkaya, A.E. (2021). Consequences of large strain anisotropic work-hardening in cold forging, International Journal of Material Forming 14, 1463-1481. DOI: 10.1007/s12289-021-01641-9

[6] https ://www.transvalor.com/fr/forge

Tools	*Programming languages : Fortran, Python.* *Mechanical Testing ; Digital Image Correlation*
Key-words	Numerical Modelling, Martensite, Bauschinger effect
Project type/ cooperation	The PhD is co-funded by VALLOUREC company and ANRT (CIFRE Grant). https://www.vallourec.com/
Skills, abilities requested	• Mechanics, Numerical Modelling. • Motivation for both computational mechanics and experimental work. • Rigor, dedication to a subject. • Aptitude to teamworking. • Proficiency in English : B2 level minimum.
Location	- MINES Paris, CEMEF, Sophia Antipolis (80%) - Vallourec One Research Centre, Aulnoye-Aymeries (20%)
CEMEF team(s)	CSM (Computational Solid Mechanics) MSR (Metallurgy, µStructures & Rheology) S&P (Surfaces & Polymers)
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