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Phase transformations, microstructure heterogeneities and resulting mechanical properties in as-quenched and tempered martensitic steels

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Martensite *Micromechanics modelling* *Tempering* *Dislocation density*

Abstract

Martensitic steels have been known and used for millennia now, but the origins of their strength and work hardening have remained a source of controversy. Since few years, the understanding of their mechanical behavior is changing paradigm. Many researchers have put into evidence the interest not to describe lath martensite as an homogeneous microstructure but more as a multiphase aggregate, a composite, resulting from the sequential nature of the phase transformation at low temperature [1,2]. According to such new schemes, the martensite behavior is controlled by the microstructural heterogeneities, ie. the spatial distribution of lath sizes, of dislocations, of carbon segregations and of carbides and not only by their mean values [3]. To these observable microstructural elements are added large distributions of hydrostatic and deviatoric internal stresses resulting from the displacive phase transformation process. This work contributes to this new movement by providing a quantitative description of these distributions in as-quenched and further tempered martensitic steels and their impact on their mechanical behaviors thanks to a complete micromechanical approach.

We have first developed a methodology to determine the dislocation densities in martensite and in austenite along the transformation by in situ HEXRD experiments. Based on a metallurgical reasoning, the spatial dislocation density distribution as well as its associated hardening were estimated for the first time [4]. In situ HEXRD tempering experiments were also performed to characterize the recovery from the as-quenched state. An original modeling approach accounting for the spatial distribution of dislocations was set up to predict their density decrease during a heat treatment.

In the same way, the microtextures of the studied microstructures were investigated by SEM-EBSD in order to assess the size distribution of the different features of martensite, as laths, blocks, packets and prior austenite grains. A statistical approach combining this latter contribution to the hardening with the one associated with dislocations explains successfully the observed distribution of the local yield strength in the as-quenched microstructures.

In situ HEXRD tempering experiments and additional APT and TEM observations were used to characterize also the respective precipitation state of transition carbides and cementite as well as the carbon segregations along heat treatments. All this experimental work has served to develop and calibrate a phase transformation model to calculate carbon segregation on dislocations, transition carbides and cementite precipitation states. Such model was for instance able to predict the suppression of transition carbide precipitation in very low carbon steels [5]. The investigation of tempering is necessary to understand the strengthening due the carbon in martensite.

Finally, our original micromechanical model describing the martensite behavior as an extended elastic/plastic transition accounts for the previous combined hardening due to size effects and dislocations, the distribution of internal stresses due to the transformation and the tempering state (relaxation, recovery, segregation and precipitation state). The model successfully explains the strength and work-hardening of the studied steels (as quenched and tempered).

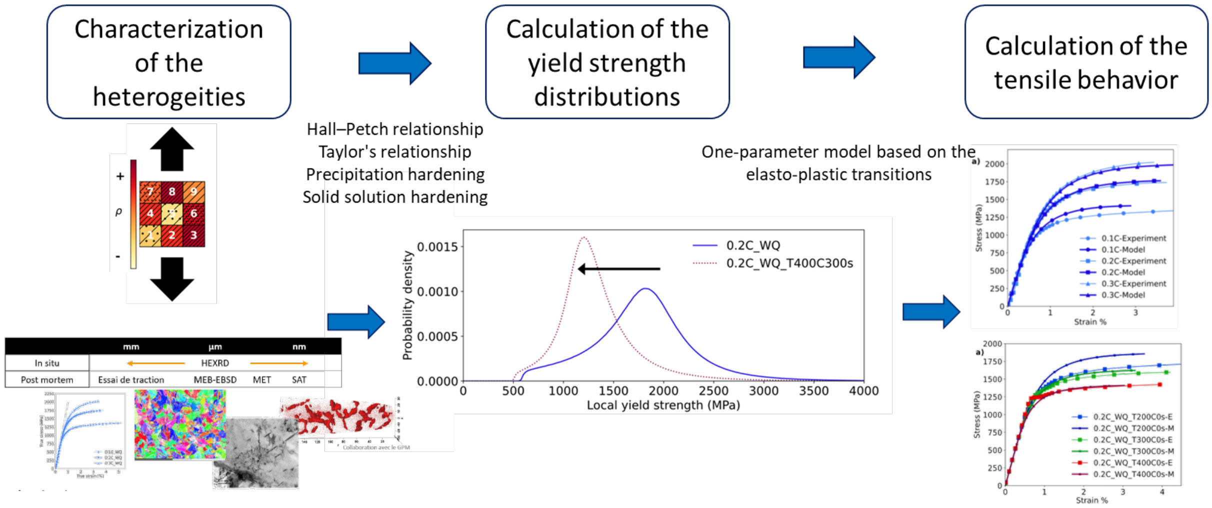

***Figure 1** – Schema of the workflow, including the multiscale characterization of the martensitic heterogeneities, the yield strength distributions and the tensile behavior calculations.*

References

[1] S.Y.P. Allain, O. Bouaziz & M. Takahashi, *ISIJ International*, 52 (2012) 717-722.

[2] L.Y. Wang, Y.X. Wu, W.W. Sun, Y. Bréchet, L. Brassart, A. Arlazarov, CR Hutchinson, *Acta Mater*, 199 (2020) 615-632

[3] L. Morsdorf, C.C. Tasan, D. Ponge, D. Raabe, *Acta Mater*, 95 (2015) 366–377.

[4] J. Macchi, S. Gaudez, G. Geandier, J. Teixeira, S. Denis, F. Bonnet, S.Y.P. Allain, *Mater. Sci. Eng. A,* 800 (2021) 140249

[5] J. Macchi, J. Teixeira, F. Danoix, G. Geandier, S. Denis, F. Bonnet, S.Y.P. Allain, *Acta Mater*, 272 (2024) 119919