IN SITU MICROMECHANICS DURING HYDROGEN CHARGING: EFFECT OF DIFFUSIBLE HYDROGEN ON BCC FE-BASED ALLOYS AND HYDROGEN PROTECTION THROUGH HYDROGEN BARRIER COATINGS

María Jazmin Duarte, Max-Planck-Institut für Eisenforschung GmbH
j.duarte@mpie.de
Jing Rao, Max-Planck-Institut für Eisenforschung GmbH
Hariprasad Gopalan, Max-Planck-Institut für Eisenforschung GmbH
Piyush Patil, Max-Planck-Institut für Eisenforschung GmbH
Christina Scheu, Max-Planck-Institut für Eisenforschung GmbH
Gerhard Dehm, Max-Planck-Institut für Eisenforschung GmbH

Key Words: hydrogen embrittlement, in situ nanoindentation, micropillar compression, hydrogen barrier coatings, Fe alloys.

Hydrogen is a strong candidate to be the energy carrier of the future; however it also represents a challenge as it might cause material degradation through hydrogen embrittlement. To mitigate the negative effects of hydrogen and propose new strategies to protect structural materials it is necessary to understand which embrittlement mechanism is dominant and its specific causes. This can be reached by studying individual hydrogen-microstructure interactions, thereby targeting analyses at the nano-/microscale during hydrogen exposure. In this talk, we will present our novel electrochemical cell design developed for this purpose (Fig. 1a). In this “back-side” charging approach, the analyzed front surface is never in contact with the solution, avoiding unwanted corrosion, and the observed effects are only due to hydrogen [1]. Hydrogen diffusion from the charged back-side towards the testing surface is quantified by permeation tests. Moreover, this unique method allows differentiating between the effects of trapped and mobile hydrogen, and performing well controlled measurements with different hydrogen levels monitored over time to consider hydrogen absorption, diffusion and release through the metal. These particular aspects will be presented with examples of nanoindentation, micropillar compression and nanoscratching tests during hydrogen charging. First, the influence of diffusible hydrogen in Fe-Cr alloys with different Cr content was evaluated through nanoindentation and pillar compression tests (Fig. 1b). Our measurements show an enhanced dislocation nucleation, consistent with the defactant theory, and a hardening effect while increasing the Cr content and the hydrogen entry. In a step forward, the Fe-Cr alloy was coated with a 1-2 µm thick layer of Al_2O_3 to study its effect as a hydrogen barrier coating. The mechanical stability of the coating was tested by nanoindentation and nanoscratching tests during hydrogen charging. While the mechanical behavior of the coating remained unaltered due to the slow hydrogen diffusion (about 9 orders of magnitude slower with respect to the Fe-Cr substrate), the accumulation of hydrogen at the substrate-coating interface might lead to local delamination at a critical load during scratching (Fig. 1c).

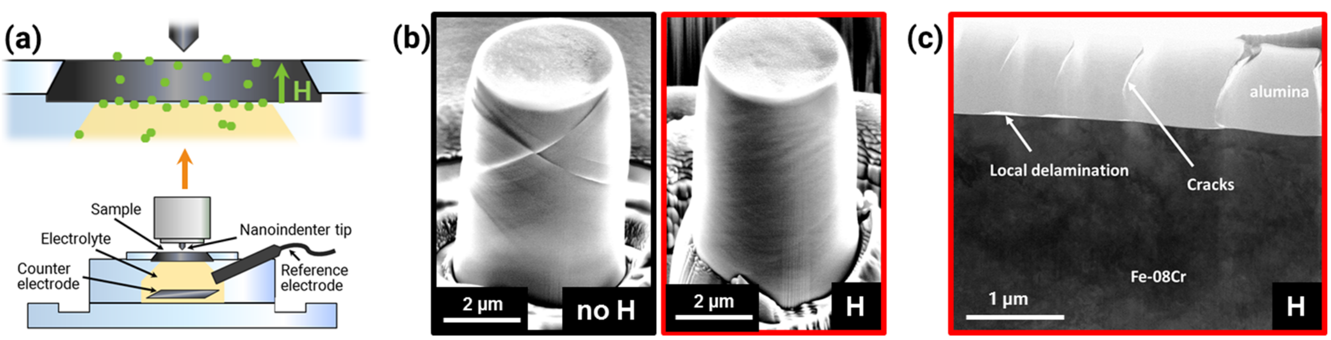

Figure 1 – (a) Schematic of the custom-made hydrogen charging cell for micromechanical testing. (b) Fe-20 wt.% Cr pillars compressed without and during hydrogen charging. (c) Nanoscratching during hydrogen charging of an Al_2O_3 coating over a Fe-8 wt.%Cr substrate.

[1] M.J. Duarte, X. Fang, J. Rao, W. 0Krieger, S. Brinckmann, G. Dehm, “In situ nanoindentation during electrochemical hydrogen charging: a comparison between front-side and a novel back-side charging approach”, J Mater Sci (2021) 56:8732–8744 8741
[2] This work was supported by the Deutsche Forschungsgemeinschaft (DFG), project no. 318876084, the European Research Council (ERC), grant no. 787446-GB-CORRELATE and the industrial collective research programme (IGF no. 10859/18), supported by the Federal Ministry for Economic Affairs and Climate Action (BMWK).