

## Electron Microscopic Investigation of Hydrogen Effects on Strain Localization and Martensitic Transformations in an Austenitic Stainless Steel.

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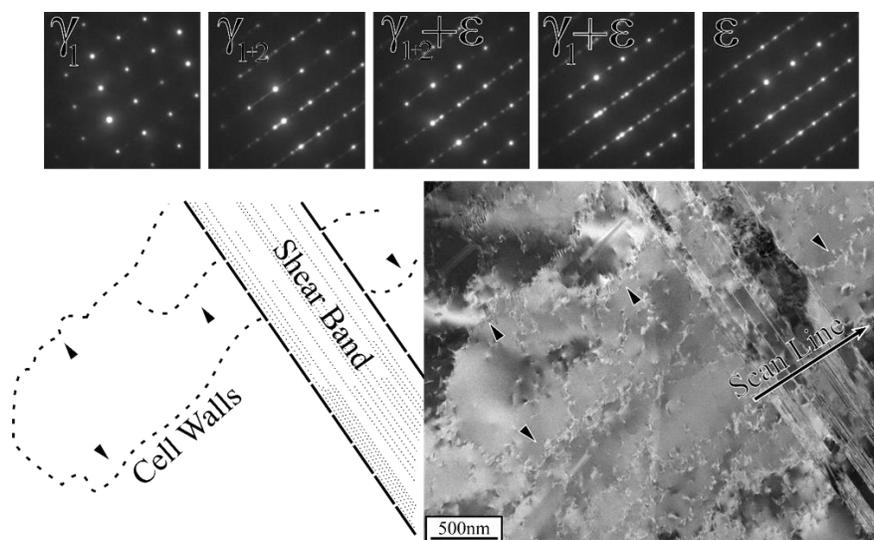
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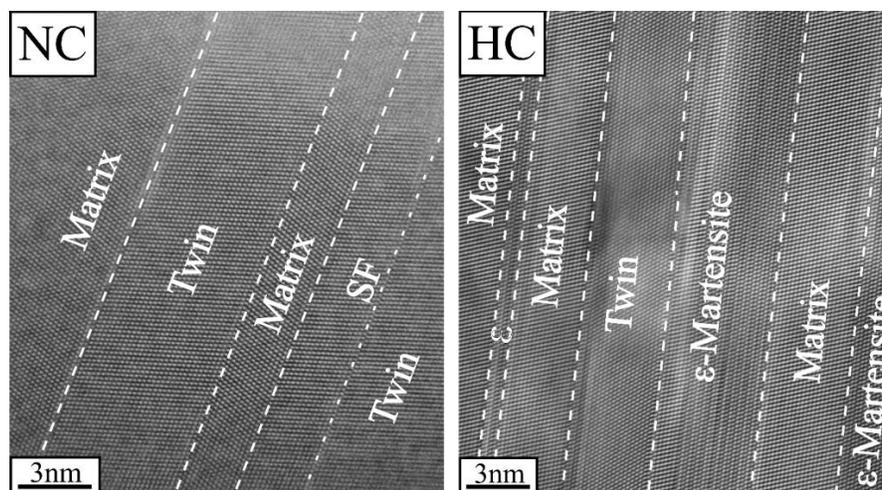
Planar deformation bands are often observed in the microstructures of deformed austenitic stainless steels. It is important to understand the formation and arrangements of these microstructural features since the heterogeneous localization of deformation can negatively impact critical mechanical properties including ductility, fatigue resistance, and fracture toughness. Deformation bands are often dominated by planar dislocation slip, but in some systems, deformation structures can also be tied to shear-coupled crystallographic transformations. Perhaps the most fundamental of these transformations is deformation twinning. Additional transformations are observed in austenitic stainless steels, such as the shear-induced transformation to hexagonal close packed (HCP)  $\epsilon$ -martensite. The interplay of strain and local atomic shuffling in these bands can also drive more complex processes, a notable example being the nucleation and growth of the  $\alpha'$ -martensite phase (a BCT structure) at the intersection of multiple deformation bands.

In this presentation, we discuss our electron microscopic investigations into the influence of hydrogen on the development of such planar deformation bands. The sensitivity of such bands to hydrogen is of interest since austenitic stainless steels are widely employed in diverse, safety critical applications for high pressure hydrogen storage and delivery. We focus on forged 304L stainless steel, comparing the evolution of the deformation microstructure with tensile strain for both hydrogen-precharged material and non-precharged material. Our analysis combines electron backscattered diffraction, diffraction contrast STEM, nanobeam diffraction, and atomic resolution STEM to provide a detailed, multiscale understanding of the microstructural evolution. We observe that the deformation band structure is different with and without the presence of internal hydrogen. In the absence of internal hydrogen, the bands are dominated by deformation twins. However, in the hydrogen-precharged material there is higher density of deformation bands and many of these contain nanoscale layers of  $\epsilon$ -martensite (as shown for instance in Figures 1 and 2) [1].

Hydrogen also affects the subsequent formation of strain-induced  $\alpha'$ -martensite in this material [2]. Our electron microscopy results suggest that hydrogen's influence on the initial nucleation may be indirect. Specifically,  $\alpha'$ -martensite is known to preferentially nucleate at the intersections of  $\epsilon$ -martensite bands [3]. Thus, any increase in tendency for forming  $\epsilon$ -martensite bands should also drive an increase in  $\alpha'$ -martensite formation, at least for the initial, nucleation stage. We will discuss in detail the structure the shear-band intersections to provide insight regarding the underlying defect mechanisms affecting the local transformations [4].



**Figure 1.** Diffraction Contrast-STEM and nanobeam diffraction patterns collected from a deformation band in a 5% strained hydrogen-charged sample. The deformation band contains both deformation twins and  $\epsilon$ -martensite. The position of the diffraction scan line is indicated. Positions of several dislocation cell walls are indicated by the small black triangles.



**Figure 2.** HAADF-STEM images of the 5% strained samples showing the internal structure of deformation bands in the non-charged (NC) and hydrogen charged (HC) specimens. The deformation bands are dominated by twinning in the NC case. Both twinning and  $\epsilon$ -martensite are observed in the HC case.

- [1] J.E.C. Sabisch, J.D. Sugar, J. Ronevich, C. San Marchi, D.L. Medlin, *Metallurgical and Materials Transactions A*, **51** (2021) 1516. doi: 10.1007/s11661-021-06170-3.
- [2] C. San Marchi, J.A. Ronevich, J.E.C. Sabisch, J.D. Sugar, D.L. Medlin, B.P. Somerday, *International Journal of Hydrogen Energy* 46 (2021) 12338. doi: 10.1016/j.ijhydene.2020.09.069.
- [3] G.B. Olson and M. Cohen, *Journal of the Less-Common Metals*, 28 (1972) 107.
- [4] Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the USDOE's NNSA under contract DE-NA-0003525.