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Hydrogen Embrittlement of Ni-Based Inconel 718 Superalloy

Hanlei Zhang, Yuankang Wang, Xin Wang, Daozheng Li and Wei Xiong*

[1.] Physical Metallurgy and Materials Design Laboratory, Department of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, PA 15261, United States
* Corresponding author: weixiong@pitt.edu; w-xiong@outlook.com

Hydrogen embrittlement prevails in metals and alloys and results in devastating mechanical failures such as cracking, which draws intensive attention from the academia and industries. Unveiling the functioning mechanisms of hydrogen embrittlement is critical for guiding the fabrication and operation of alloys, thereby calling for urgent research efforts. In this work, we studied the effects of hydrogen addition on the compression of a Ni-based Inconel 718 superalloy. Hydrogen was introduced into the alloy via electrochemical charging using a H_3PO_4-based electrolyte, at a current rate of 15 mA/cm^2 for 160 h. Cold compression of ε = 15% was carried out on the hydrogen-free and hydrogen-containing samples, and the difference in their deformation behavior was compared by microstructural analysis using Transmission electron microscopy (TEM) and electron backscatter diffraction (EBSD).

The results indicate that the addition of hydrogen into the Inconel 718 superalloy suppresses the twinning behavior, while the dislocation slipping was activated instead. This conclusion is evidenced by measurement of the twin and dislocation densities in the hydrogen-free and hydrogen-containing samples, as shown in Figure 1. Figure 1(a) compares the twin densities within the hydrogen-free and hydrogen-containing alloys. Compared with the hydrogen-free alloy, the hydrogen-containing alloy exhibits persistently lower twin densities at three selected locations (surface, subsurface (100 µm from the surface) and bulk (200 µm from the surface)), confirming the suppression of hydrogen on twinning. According to Figure 1(b), the hydrogen-containing sample exhibits a much higher dislocation density compared to the hydrogen-free sample, indicating that dislocation slipping replaces twinning as the major mechanism to accommodate the mechanical deformation in the hydrogen containing alloy, as twinning is largely suppressed.

The accelerated dislocation slipping in the hydrogen-containing alloy leads to pronounced accumulation of dislocations along the twin boundaries, as demonstrated by the TEM view in Figure 2(a). As twin boundaries are barriers for the dislocation slipping, a high concentration of dislocations get stuck along the twin boundary. The regions away from the twin boundary have no such dislocation accumulation because the dislocations can pass through these regions smoothly, as marked by a yellow circle in Figure 2(a). The accumulation of dislocations results in an intensive concentration of lattice distortion along the twin boundary, which eventually breaks the twin boundary and turns it into a crack, as demonstrated by the zoom-out and zoom-in TEM views in Figures 2(a, b). The high concentration of dislocations along the crack face (Figure 2(b)) confirms the hydrogen-induced dislocation concentration and cracking.

We conclude that the addition of hydrogen in the Ni-based Inconel 718 superalloy suppresses the deformation twinning and instead accelerates the dislocations slipping. Consequently, a high concentration of dislocations accumulates along the twin boundaries in the hydrogen-containing alloy, which leads to a concentration of lattice distortion along the twin boundary and eventually cracking. This work elucidates a fundamental working mechanism of hydrogen embrittlement in the Ni-based Inconel 718 superalloy, which is essential knowledge in guiding the design, fabrication, and operation of

Ni-based alloys [1-3].

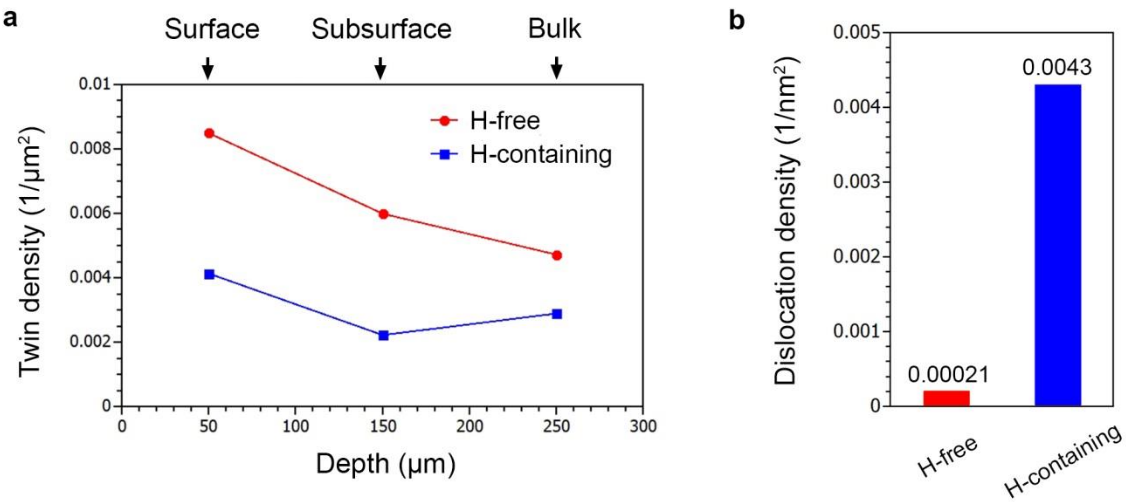

Figure 1. Comparing the compression behavior of hydrogen-free and hydrogen-containing samples. (a) Diagram comparing the twin densities of the hydrogen-free and hydrogen-containing samples, indicating that the addition of hydrogen suppresses the twinning. (b) Histogram comparing the dislocation densities of the hydrogen-free and hydrogen-containing samples, showing a significantly reduced dislocation density within the hydrogen-containing sample.

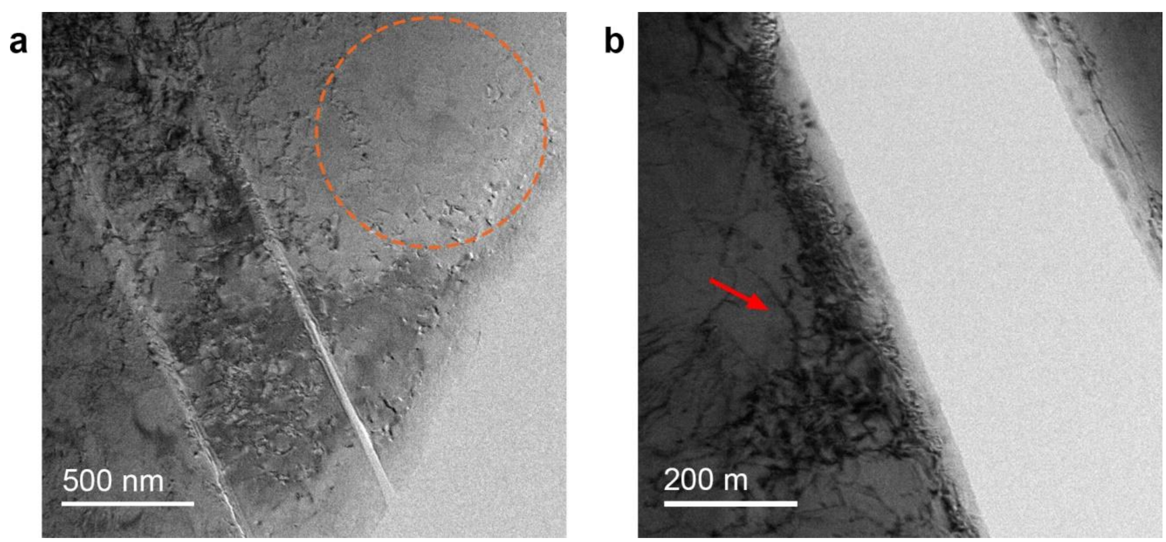

Figure 2. Microcracking within the hydrogen-containing Inconel 718 alloy. (a) TEM view of microcracks developing along twin boundaries. (b) Zoom-in bright-field TEM view showing the accumulation of dislocations a crack face, confirming its role in inducing the cracking along twin boundaries.

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