IN-SITU MICROCANTILEVER BENDING OF TITANIUM REVEALING HYDROGEN-DISLOCATION INTERACTIONS

Liesbet Deconinck, Research Group of Sustainable Materials Science, Ghent University
Liesbet.Deconinck@UGent.be
Xu Lu, Norwegian University of Science and Technology
Dong Wang, Norwegian University of Science and Technology
Roy Johnsen, Norwegian University of Science and Technology
Kim Verbeken, Research Group of Sustainable Materials Science, Ghent University
Tom Depover, Research Group of Sustainable Materials Science, Ghent University

Key Words: titanium; micromechanical properties; in-situ testing; cantilever bending
Despite the excellent mechanical properties and corrosion resistance of titanium, this metal suffers from hydrogen assisted degradation and premature failure [1]. Extensive macromechanical testing on the interaction between hydrogen and titanium has been reported [2], proposing multiple hydrogen assisted degradation mechanisms, including hydrogen enhanced localized plasticity (HELP), stress induced hydride formation (SIHF) and hydrogen enhanced decohesion. However, smaller scale testing is required to obtain nanoscale insights in the hydrogen assisted crack initiation and propagation. Meanwhile, the concept of in-situ cantilever bending has been applied on other metals [3, 4] to investigate local hydrogen-dislocation interactions. However, no such small scale research has been reported on titanium yet. Moreover, titanium is in particular prone to the formation of a brittle hydride phase in a stressed hydrogen-rich environment. Zhu et al. [5] mentioned in a recent review the need for similar micromechanical testing to characterize hydrogen-dislocation interactions in titanium. Therefore, the aim of this work was to reveal the hydrogen effect on the micromechanical properties with the corresponding embrittling mechanism, by using advanced characterization methods. The impact of hydrogen on the micromechanical characteristics of monophasic grade 2 titanium was assessed by fabricating micrometer sized cantilevers in a single grain with focused ion beam milling. As such, biases from grain boundaries and other polycrystalline features are excluded [4]. The prenotched beams were bent, comparing a reference condition in air and in-situ hydrogen charging. Specific grain orientations were evaluated, i.e. one orientation promoting basal type hydride formation, and the other one discouraging hydride formation. The post-mortem characteristics were in detail assessed by scanning transmission electron microscopy and transmission Kikuchi diffraction. Due to the small cantilever geometry, the failure could be characterized as a whole, including all dislocation activity and plasticity evolution involved, which could furthermore be uniquely mapped to the mechanical data [6]. Several failure stages were distinguished in the mechanical load-displacement curves. Firstly, in the elastic loading phase, no plastic deformation occurred. Secondly, a plateau phase was reached, explained by the competing effects of active plastic deformation, and the reducing cantilever cross-section. Here, dislocations were generated at the notch tip upon loading and microcracks nucleated. Finally, in the last stage, the crack propagated, laboriously in air, while significantly accelerated in-situ. Specimens failed in air showed a ductile failure behavior with slip lines present in agreement to the theoretic deformation modes. The notch blunted considerably by creating extensive dislocation tangles while accommodating plastic deformation. On the other hand, hydrogenated specimens fatally suffered from hydrogen induced degradation. Hydrogen accumulated at the crack tip and decreased the dislocation mobility by pinning dislocations. The crack tip sharpened and propagated in a brittle way. Furthermore, SIHF at the crack tip and contributed to failure. Also indications for the HELP mechanism were observed in the poorly hydride forming grain orientation. As such, the results contributed to the understanding of the intrinsic impact of dislocations on the behavior of hydriding and hydrogen assisted failure.

ADDIN Mendeley Bibliography CSL_BIBLIOGRAPHY [1] H. G. Nelson, *Treatise on Materials Science and Technology*, vol. 25, Academic Press, 1983, pp. 275–359. doi: 10.1016/b978-0-12-341825-8.50014-3.
[2] C. L. Briant, Z. F. Wang, and N. Chollocoop, *Corros. Sci.*, vol. 44, pp. 1875–1888, 2002, doi: 10.1016/S0010-938X(01)00159-7.
[3] Y. Deng and A. Barnoush, *Acta Mater.*, vol. 142, pp. 236–247, 2018, doi: 10.1016/j.actamat.2017.09.057.
[4] X. Lu, D. Wang, Z. Li, Y. Deng, and A. Barnoush, *Mater. Sci. Eng. A*, vol. 762, p. 138114, 2019, doi: 10.1016/j.msea.2019.138114.
[5] Y. Zhu, T. W. Heo, J. N. Rodriguez, P. K. Weber, R. Shi, B. J. Baer, F. F. Morgado, S. Antonov, K. E. Kweon, E. B. Watkins, D. J. Savage, J. E. Chapman, N. D. Keilbart, Y. Song, Q. Zhen, B. Gault, … B. C. Wood, *Curr. Opin. Solid State Mater. Sci.*, vol. 26, no. 6, p. 101020, 2022, doi: 10.1016/j.cossms.2022.101020.
[6] T. Hajilou, Y. Deng, B. R. Rogne, N. Kheradmand, and A. Barnoush, *Scr. Mater.*, vol. 132, pp. 17–21, 2017, doi: 10.1016/j.sc
riptamat.2017.01.019