Hydrogen embrittlement mechanisms of nitrogen-doped ferrite/austenite duplex steels with different pre-strains

Hydrogen embrittlement behavior of a nitrogen-doped ferrite/austenite duplex stainless steel was investigated in this study. Significant hydrogen embrittlement occurred, the cracking behavior was deformation twins and ferrite/austenite. Interestingly, the preferential hydrogen localization site and cracking sites could be altered by pre-straining, which is expected to be used to develop hydrogen-resistant high-strength steels.

Prevention of hydrogen embrittlement is an urgent issue to increase durability of high-strength steels for automobiles and hydrogen-energy-related infrastructures. An effective route to suppress the hydrogen embrittlement is developments of new high-strength hydrogen-resistant steels. In this context, microstructure and alloy design strategies for the hydrogen-resistant steels have been noted in these days. In particular, an introduction of austenite and an addition of solute nitrogen are key to achieve the high-strength with a superior hydrogen resistance. In this study, we characterized the hydrogen-related cracking behavior and associated microstructure evolution in a nitrogen-doped ferrite/austenite duplex stainless steels.

Hydrogen charging in an aqueous solution of 3%NaCl+3g/L NH_4SCN at 10 A/m^2 for 7 days introduced 498 mass ppm diffusible hydrogen, and decreased the total tensile elongation from 29% to 6%. That is, hydrogen embrittlement occurred with this condition. Figure 1(a) shows a phase map exhibiting hydrogen-induced cracks and surrounding microstructure. The preferential crack initiation sites were deformation twins in austenite and ferrite/austenite interfaces (e.g. Fig. 1(b)). The hydrogen-induced cracking behavior was unconventional compared to that of other ferrite/austenite duplex stainless steels that did not contain solute nitrogen. Therefore, it was considered that the characteristic hydrogen embrittlement behavior was attributed to the addition of solute nitrogen.

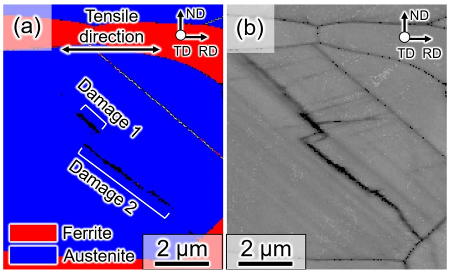

Fig.1 Micrographs obtained by electron backscatter diffraction measurements for the hydrogen-charged and fractured specimen: (a) Phase, and (b) image quality (IQ) maps [1]. The dark lines regions in the austenite in the IQ map indicate cracks and deformation twins.

In addition, we carried out the same hydrogen embrittlement tests for the duplex steels with different pre-strains. Interestingly, the 22% pre-strain effect coupled with solute nitrogen achieved 1 GPa tensile strength even under the effect of hydrogen. More specifically, the pre-strain changed the preferential crack initiation site to ferrite, and suppressed the hydrogen diffusion in austenite (Fig. 2). The pre-strain effects on the cracking behavior and hydrogen diffusivity may play an important role to improve the resistance to hydrogen embrittlement of the nitrogen-doped duplex steel.

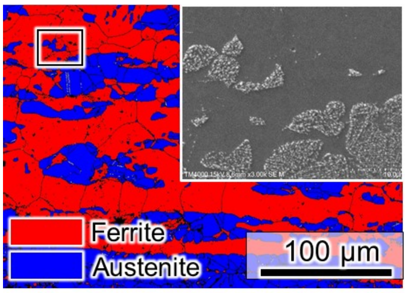

Fig. 2 Phase map and secondary electron image (inset) showing deposition of silver particles in the hydrogen-charged duplex steel with 22% pre-strain. The location of the image shown as the inset corresponds to that highlighted by the black square in the phase map. When hydrogen flux is high, silver particles are preferentially deposited on the surface consisting of the specific microstructure, which is called silver decoration technique [2]. The silver decoration experiment was carried out by immersing the hydrogen-charged specimen into an aqueous solution of 4.3 mM $Ag[K(CN)_2]$.

References

[1] M.Y. Maeda, M. Koyama, H. Nishimura, O.M. Cintho and E. Akiyama, Int. J. Hydrog. Energy. 46, 2716 (2021).
[2] M. Koyama, M. Rohwerder, C.C. Tasan, A. Bashir, E. Akiyama, K. Takai, D. Raabe and K. Tsuzaki, Mater. Sci. Technol. 33, 1481 (2017).

Keywords: steel; strength; embrittlement
Milene Yumi Maeda (State University of Ponta Grossa), Motomichi Koyama (Environmentally Robust Materials, Institute for Materials Research)
E-mail: koyama@imr.tohoku.ac.jp