IMPROVEMENT OF RESISTANCE AGAINST HYDROGEN EMBRITTLEMENT BY INCREASING CARBON SEGREGATION AT PRIOR AUSTENITE GRAIN BOUNDARY IN LOW-CARBON MARTENSITIC STEELS

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High-strength steels, such as martensitic steels, are highly susceptible to hydrogen embrittlement, so that it is desired to improve their resistance against hydrogen embrittlement for wide application of high-strength steels. Lath martensite is a typical microstructure of low- and medium-carbon high-strength steels. A lath martensitic structure consists of several structural units with different size scales, namely, lath, block, packet, and prior austenite grain. Although martensitic structure contains several types of boundaries, the hydrogen-related intergranular fracture occurs mainly along prior austenite grain boundaries (PAGB). Recently, first-principles calculations have revealed that carbon segregation in iron suppressed the reduction of GB cohesive energy by hydrogen [1]. However, it has not yet been verified whether carbon segregation at PAGB is effective or not in reducing susceptibility to hydrogen embrittlement in martensitic steels. The present study experimentally demonstrated that the resistance against hydrogen embrittlement in martensitic steels can be improved by increasing carbon segregation at PAGB [2].

An Fe-3Mn-0.2C (wt.%) alloy was heat-treated in two different ways. One is one-step austenitization; the specimen was austenitized at 1100 °C for 30 min, followed by ice-brine quenching (Non-seg specimen). The other is two-step austenitization; the specimen was held at 790 °C (just above A_3) for 30 min following the austenitization (1100 °C, 30 min), and then ice-brine quenched (Seg specimen). The isothermal-holding at 790 °C aimed at increasing carbon segregation at (prior) austenite grain boundaries. The average sizes of lath (W_{lath}), block (W_{block}), packet (D_{packet}), and PAG (D_{PAG}) were almost the same between the Non-seg and Seg specimens, respectively (Non-seg: W_{lath} = 0.478 μm, W_{block} = 4.44 μm, D_{packet} = 68.6 μm, D_{PAG} = 183 μm, Seg: W_{lath} = 0.469 μm, W_{block} = 3.62 μm, D_{packet} = 81.3 μm, D_{PAG} = 187 μm). The concentration of segregated carbon at PAGB evaluated using 3DAP was higher in the Seg specimen (5.84 at.%) than that in the Non-seg specimen (3.62 at.%). Sheet-type tensile test specimens were cathodically pre-charged with hydrogen in an aqueous solution of 3% NaCl + 3 gL^{-1} NH_4SCN for 24 h at a current density of 0.5 Am^{-2}. The diffusible hydrogen content (H_D) was 0.477 wt. ppm in the Non-seg specimen, which were nearly the same as that in the Seg specimen (0.489 wt. ppm). In the uncharged specimens, there were no significant differences in the ultimate tensile strength and the total elongation between the Non-seg and Seg specimens (Non-seg: 1523 MPa and 8.8%, Seg: 1530 MPa and 8.6%). In contrast, in the hydrogen-charged specimens, the maximum tensile stress was higher in the Seg specimen (1186 MPa) than that in the Non-seg specimen (666 MPa) though the H_D were similar values. In addition, the fraction of intergranular fracture surface was 11.3% in the Seg specimen, which was significantly reduced from that in the Non-seg specimen. Based on these results, we concluded that the segregated carbon suppressed the accumulation of hydrogen around PAGB by site competition and increased the cohesive energy of PAGB, leading to the significantly improved resistance against hydrogen-related intergranular fracture.

Reference

[1] M. Yamaguchi and J. Kameda, “Intergranular decohesion induced by mobile hydrogen in iron with and without segregated carbon: first-principles calculations”, *International Hydrogen Conference (HIC 2012): Hydrogen-Materials Interactions*, American Society of Mechanical Engineers (ASME) Press (2014), 747.
[2] Kazuho Okada, A. Shibata, T. Sasaki, H. Matsumiya, K. Hono, and N. Tsuji; “Improvement of resistance against hydrogen embrittlement by controlling carbon segregation at prior austenite grain boundary in 3Mn-0.2C martensitic steels”, *Scripta Materialia*, 224(2022), 115043.