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Behavior of Hydrogen and Lattice Defects from Incubation Period to Fracture in Hydrogen Embrittlement of High-Strength Steels

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The role of hydrogen in the formation behavior of various lattice defects induced by plastic strain in pure iron specimens has been investigated using low-temperature thermal desorption spectroscopy (L-TDS), which can start measurement from −200 ºC. Specimens were subjected to various plastic strains within a uniform elongation range in the absence and presence of hydrogen. Strain-induced lattice defects were quantitatively evaluated using L-TDS for specimens saturated with hydrogen as a probe for detecting lattice defects, not only vacancies but also dislocation cores. The L-TDS spectra contained two hydrogen desorption peaks: a low-temperature peak associated with dislocations and a high-temperature peak associated with vacancies. The tracer hydrogen content corresponding to each peak increased with plastic strain. However, when compared at the same plastic strain of 25%, the low-temperature peak, i.e., dislocations, was not enhanced by hydrogen, whereas the high-temperature peak, i.e., vacancies, was enhanced by hydrogen, increasing by about six times at 25% plastic strain and by seven times at 40% plastic strain. Analyses conducted by electron channeling contrast imaging (ECCI) and electron backscattered diffraction (EBSD) revealed that strain was localized along the vicinity of the ferrite grain boundaries at 25% plastic strain in the presence of hydrogen. Hence, the role of hydrogen in the formation behavior of plastic strain-induced lattice defects is presumably to enhance vacancy formation and the localization of the dislocation configuration near the grain boundaries without affecting the amount of dislocations formed.

In addition, an attempt was made to separate and identify hydrogen peaks desorbed from plastic-strained, hydrogen-enhanced lattice defects from among various trapping sites in tempered martensitic steel showing quasi-cleavage fracture using L-TDS. The amount of the lattice defects beneath the quasi-cleavage fracture surface was measured by L-TDS. The L-TDS results made it possible to separate two peaks, namely, that of the original desorption and also that of new desorption from the steel specimens due to the application of plastic strain in the presence of hydrogen. The new desorption obtained by L-TDS corresponded to vacancy-type defects. Hydrogen and plastic strain noticeably enhanced lattice defects formed within 1.5 mm from the fracture surface, where the average concentration of vacancy-type defects reached approximately 10^{-5} order in terms of atomic ratio. These results indicate that the accumulation of excess vacancy-type defects enhanced by hydrogen in the local region can lead to nanovoid nucleation and coalescence in plastic deformation, resulting in quasi-cleavage fracture of tempered martensitic steel.

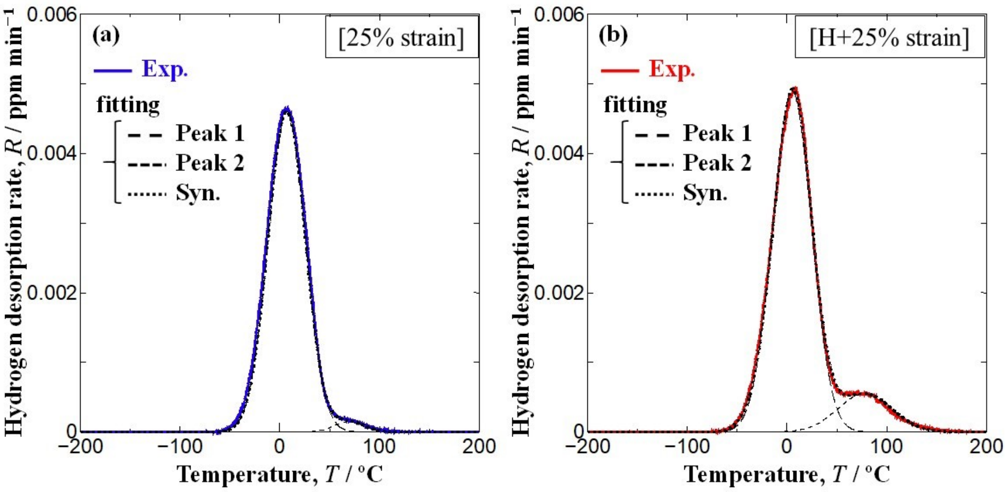

Fig.1 Peak separation using Gaussian fitting for (a) 25% strain and (b) H+25% strain specimens. The curves indicated by “Exp.” are experimental. The two fitted Gaussian curves are denoted as “Peak 1” and “Peak 2”. The synthesized curves of the Gaussian curves are denoted as “Syn.”.