EFFECT OF HYDROGEN CHARGING ON AMBIENT AND CRYOGENIC MECHANICAL PROPERTIES OF A PRECIPITATE-STRENGTHENED AUSTENITIC STEEL

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ABSTRACT

The method of high-pressure hydrogen charging was used to charge hydrogen into smooth and notched tensile specimens of γ' precipitate-strengthened austenitic steel JBK-75. The hydrogen content in the charged specimens was 25.2 ppm (by weight). In the test temperature range 293 to 77 K, hydrogen had no obvious effect on strength, but it caused some decrease in ductility at 223 to 295 K. The steel is not notch sensitive, and hydrogen charging had little effect on notch sensitivity at ambient and low temperatures. With decreasing temperature, both strength and ductility increased, and hydrogen damage greatly decreased. Increasing the aging temperature and time tends to increase the hydrogen damage of the steel, but hydrogen had less effect on aged strength. The steel that had been given an appropriate heat treatment had excellent cryogenic mechanical properties and resistance to hydrogen damage. The steel had very stable microstructure at low temperatures; no phase transition occurred as a result of strain and hydrogen at 293 to 77 K. Fine grain and fine γ' precipitates decreased hydrogen damage; the presence of η phase at grain boundaries increased hydrogen damage.

INTRODUCTION

Hydrogen embrittlement (HE) of precipitate-strengthened austenitic steel (PSAS) has received considerable attention.1-4 The reason may be the low matrix and weld strength of single-phase austenitic steel; in spite of its resistance to HE, its yield strength is usually less than 400 MPa. There are expected to be a variety of applications in hydrogen environments (including pumps, valves, and special vessels) that will demand higher strength steel. Thus, an austenitic matrix strengthened by precipitation might be selected not only for its high strength but also for its hydrogen compatibility and easy formability and weldability. One such steel is A-286, which has the highest strength of the PSAS. JBK-75 steel has evolved to improve the weldability and hydrogen compatibility of A-286. Some research on the hydrogen compatibility of these two steels has been reported,1,3 but no attention has been paid to the relation between PSAS aging characteristics and hydrogen damage (HD). There was one report on the occurrence of cryogenic HE in austenitic steel.5 Whether HE would occur under the interaction of hydrogen, low temperatures, and strain must be considered for cryogenic vessels containing hydrogen.
The purposes of this study were (1) to understand the tendency for HD in one PSAS, JBK-75, at ambient and cryogenic temperatures, (2) to determine how to reduce HD, and (3) to identify the relationship between the microstructure and HD.

EXPERIMENTAL PROCEDURES

The nominal composition of the JBK-75 steel tested was Fe-30Ni-15Cr-1.5Mo-2.0Ti-0.25Al-0.25V-0.002B. Specimens were taken from hot-rolled bar stock, 20 mm in diameter. Smooth, tensile specimens were 5 mm in diameter with a gage length of 25 mm. Notched tensile specimens were 5 mm in diameter at the notch; the notch was 60°, 1 mm deep, with a root radius of 0.1 mm; the stress concentration factor for the notch was 4.55. All specimens were solution-treated at 1253 K for 1 h and then water quenched. Specimens for cryogenic tests were aged 8 h at 1013 K and then air cooled. The average austenite grain size and γ' precipitate sizes were about 33 μm and 6 to 11 nm, respectively.

The aged specimens were hydrogen charged in an autoclave at 573 K and 10 MPa in high-purity hydrogen for 4 days. The hydrogen contents in the specimens before and after charging were 0.9 and 25.2 ppm (by weight), respectively. Results of hydrogen analysis indicated that, for the 5-mm-diameter specimen, hydrogen concentration saturated after hydrogen charging. About 1% of the hydrogen was released after the charged specimens had been exposed to ambient conditions for 7 days.

After hydrogen charging, the specimens were kept at different low temperatures for 15 min, and then tensile tests were conducted at a crosshead rate of 2.5 mm/min. Diffraction analyses of the specimens deformed at cryogenic temperatures were conducted with a Philips PW 1140 X-ray diffractor; the specimen surfaces had been electrolytically polished before they were analyzed. Foil specimens were analyzed by a EM420 TEM operating at 100 kV. The $\psi_L$ and $\delta_L$ parameters were used to evaluate the HD of the PSAS, where $\psi_L$ and $\delta_L$ are the loss rates of reduction of area (RA) and elongation, respectively, for smooth tensile specimens. The definition of the loss rate for a property is

$$\frac{\text{uncharged property} - \text{charged property}}{\text{uncharged property}}$$

RESULTS AND DISCUSSION

Effect of Hydrogen on Cryogenic Tensile Properties

The effect of hydrogen charging on the ambient and cryogenic tensile properties of JBK-75 steel is shown in Table 1. Hydrogen had no effect on the yield strength ($a_{0.2}$) and ultimate tensile strength ($a_b$) at different temperatures. Although hydrogen results in some loss of ductility, the degree of loss depended on the test temperature. As temperature decreased, both strength and ductility increased. Figure 1 shows the HD tendency for the steel at cryogenic temperatures: The steel was not very sensitive to HD at room temperature, and the HD decreased with decreasing temperature. At temperatures less than 223 K, $\psi_L$ was less than 10% and $\delta_L$ was less than 5%.

The very low tendency of JBK-75 steel to HD at cryogenic temperatures can be explained by dislocation theory. During deformation, mobile dislocations can carry hydrogen atoms (in the "Cottrell atmosphere"). Near room temperature, hydrogen atoms are moved by dislocations and transferred to obstacles (e.g., grain boundaries, phase boundaries, and inclusions). The