

Effect of nickel on hydrogen embrittlement behavior of medium-carbon high strength steels

Weijun Hui*, Haixu Zhang, Yongjian Zhang, Xiaoli Zhao, Chengwei Shao

School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, PR China

ARTICLE INFO

Article history:

Received 10 June 2016

Received in revised form

6 August 2016

Accepted 7 August 2016

Available online 8 August 2016

Keywords:

Nickel

Hydrogen embrittlement

Delayed fracture

High strength steel

Corrosion

ABSTRACT

The present study was attempted to explore the influence of Ni up to 1% on hydrogen embrittlement (HE) behavior of medium-carbon high strength steel by using both constant load test (CLT) and slow strain rate test (SSRT). The results show that HE index (HEI) decreases notably with the addition of 0.55% Ni, and this decreasing tendency tends to slow down with the addition of 1.02% Ni. HEI of SSRT is comparatively higher than that of CLT. The fraction of brittle crack initiation area decreases with increasing Ni content. There is a decreasing tendency of both absorbed hydrogen content in Walpole solution and pre-charged hydrogen content with the addition of Ni. Both corrosion rate and pit depth of specimens after immersed in Walpole solution tend to decrease with increasing Ni content. Further electrochemical polarization test reveals that adding Ni could enhance pitting corrosion resistance. It is concluded that the addition of Ni could further lower the HE susceptibility of the tested steels mainly owing to enhanced corrosion resistance and decreased hydrogen absorption.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In service delayed fracture (DF) of structural components such as high strength bolts caused by hydrogen embrittlement (HE), or in other words, hydrogen-induced delayed fracture (HIDF) has long been one of the most frustrating problems for both consumers and manufactures [1–5]. The susceptibility to HE generally increases with enhancing steel strength level, and therefore the strength level of high strength bolts had been limited to about 1000–1200 MPa [2,3]. Nowadays the application of high strength steels in hydrogen-rich environments is becoming increasingly important. Moreover, with the development of modern industry, there is an increasing demand for higher strength steels with tensile strength exceeding about 1200 MPa to be used for high strength components and structures, mainly for the purposes of higher performance, weight reduction and cost saving [3]. Therefore, great efforts have been made to develop higher strength steels with superior HE resistance [3,6–8].

There are several factors affecting the HE susceptibility such as environment, stress and material. In the development of HE resistant high strength steels, a rational approach can be taken in response to the HE process composed of the entry of hydrogen, the transportation and accumulation of hydrogen to stress concentrated region such as prior austenite grain boundaries, and the

formation of cracks [3,9]. The proposed approaches usually comprise: 1) preventing the entry of hydrogen; 2) rendering the absorbed hydrogen immobile (hydrogen trapping effect); and 3) improving microstructural homogeneity such as grain boundary properties (grain boundary strengthening) [2–4,6,7,9]. It has been confirmed that the addition of microalloying elements such as V, Ti and Nb is an effective method to improve the HE resistance of high strength steels mainly through hydrogen trapping mechanism [3,10–17]. Moreover, our previous work has proved that the pronounced effect of alloying element Mo on raising the tempering resistance and strengthening prior austenite grain boundary are the main reasons for the beneficial effect of Mo on improving HE resistance of V and Nb microalloyed 40Cr steel [18].

However, most of these studies were focus mainly on hydrogen trapping and grain boundary strengthening effects. As for preventing the entry of hydrogen into steel, efforts were paid mainly by the application of a plating layer over the steel surface as diffusion barriers to the ingress of hydrogen [1,4,9,19]. Shiraga et al. recently reported the beneficial effect of Ni on improving HIDF resistance of 1420 MPa grade bar steel for prestressed concrete in the as-heat-treated condition [20]. However, there are still controversial about the effect of Ni addition on sulfide stress cracking (SSC) resistance though its detrimental effect on SSC has been reported since the beginning of the study of SSC, and according to NACE Standard MR-01-75 the addition of Ni was limited to no more than 1% [21–25]. The influence of Ni has been discussed mainly from the microstructure viewpoint, that is, Ni is a strong austenite-forming element and it then reduces the lower critical

* Corresponding author.

E-mail address: wjhui@bjtu.edu.cn (W. Hui).

temperature A_{c1} , and it also has a strong tendency to cause banded structures. Therefore, Ni per se has no adverse effect on SCC unless the tempering temperature in the banded area exceeds the A_{c1} temperature causing the formation of fresh untempered martensite [21].

Ni is a widely used alloying element in structural steels mainly owing to its beneficial effects on hardenability and toughness. Therefore, it is worthwhile to further study the influence of Ni on the HE resistance of high strength structural steels. In the present study, both constant load test (CLT) and slow strain rate test (SSRT) were employed to investigate the effect of Ni up to 1% on the HE susceptibility of newly developed 1500 MPa grade high strength steel 42CrMoVNb, in an attempt to further enhance its HE resistance so as to extending its application. It is also beneficial to gain a deeper insight of HE behavior as well as providing a new possible way of improving HE resistance of high strength steels.

2. Material and experimental procedure

2.1. Materials and specimen preparation

The chemical compositions of the tested steels with varying Ni additions up to about 1%, which were designated as N1, N2 and N3, are listed in Table 1. The base steel, N1, is newly developed 1500 MPa grade high strength steel featured by V and Nb micro-alloying and a litter higher Mo content compared with conventional steel 42CrMo (AISI 4140) [7]. The tested steels were melted in a vacuum-induction furnace of 250 kg capacity and then casted into 110 kg ingots. These ingots were reheated to 1230–1250 °C and held at that temperature for at least 1 h and then press forged to rods with diameter of 18 mm. Circumferentially notched round specimens, as shown in Fig. 1 with notch root radius of 0.15 mm ($K_t=3.2$) [26], were used for the CLT and SSRT. Specimens for tensile testing are standard round bar with minimum diameter of 5 mm and gauge length of 25 mm. Specimens with diameter of 5 mm and length of 15 mm were used to study the hydrogen absorption, desorption and corrosion behavior.

All the specimens were austenitized at 945 °C for 45 min in an electric resistance furnace, oil quenched and then tempered at 600 °C for 90 min followed by air cooling, which were selected based on previous investigations [3,7]. These heat treatments were conducted after pre-machining to close to the final shapes of the specimens but leaving a finishing allowance, unless otherwise indicated. To minimize the influence of surface roughness as lower as possible, the surface of the as-polished specimens was polished in the axial direction with sand abrasive papers (600 grit to 1000 grit) after QT treatment (termed as-polished specimen hereinafter). Part of the specimens were machined to the final shape and then heat treated in order to study the influence of surface state on HE performance, and these specimens were termed as as-heat-treated specimens hereinafter. Hydrogen was introduced into the thermal desorption spectrometry (TDS) and SSRT specimens by electrochemical charging in a 0.1 mol/L NaOH aqueous solution at 4 mA/cm² current density for 72 h.

Table 1
Chemical compositions of the tested steels (wt%).

Steel	C	Si	Mn	P	S	Cr	Ni	Mo	V	Nb
N1	0.43	0.19	0.52	0.005	0.005	1.05	–	0.35	0.25	0.03
N2	0.42	0.20	0.52	0.005	0.005	1.05	0.55	0.36	0.25	0.03
N3	0.43	0.20	0.51	0.005	0.005	1.06	1.02	0.36	0.25	0.03

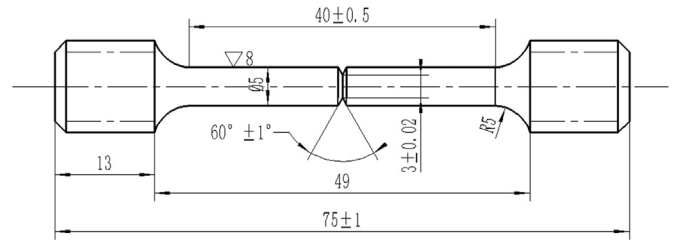


Fig. 1. Geometry and dimensions (in mm) of the notched specimen with notch root radius of 0.15 mm and $K_t=3.2$.

2.2. Measurement of HE susceptibility and hydrogen content

SSRT was performed at room temperature using a WDML-100 kN type machine at a nominal strain rate of 2.1×10^{-6} /s. The results were the average of at least four specimens. After SSRT, the notch tensile stresses (σ_{NS0} and σ_{NS} for the uncharged and hydrogen-charged specimens, respectively) were obtained. The index of relative susceptibility to HE for SSRT (HEI_s) was determined by calculating the relative notch tensile strength loss, which is expressed as:

$$HEI_s(\%) = \left(1 - \frac{\sigma_{NS}}{\sigma_{NS0}} \right) \times 100\% \quad (1)$$

CLT was carried out in a Walpole solution (mixing of sodium acetate and hydrochloric acid aqueous solution) with pH value of 3.5 to evaluate the HIFD resistance. The critical delayed fracture stress in X hours (here X=100 h), σ_{NC} , which is adopted as an index of HE resistance value, is defined as follow [3,7]:

$$\sigma_{NC} = (\sigma_f + \sigma_n)/2 \quad (2)$$

where σ_f is the minimum stress under which the delayed fracture occurs in X h and σ_n is the maximum stress under which delayed fracture does not occur in X h. At least 10 specimens were prepared for each condition. The index of relative susceptibility to HE for CLT (HEI_C) was also used to evaluate the HE susceptibility in this study, which reads:

$$HEI_C(\%) = \left(1 - \frac{\sigma_{NC}}{\sigma_{NCO}} \right) \times 100\% \quad (3)$$

where σ_{NCO} is the maximum fracture stress in air compared with that of σ_{NC} in solution.

TDS was used for the analysis of hydrogen and the tests were carried out within 10 min after completing the hydrogen charging. The specimen was heated from ambient temperature to 800 °C at a constant heating rate of 100 °C/h. The hydrogen effusing out of the specimen was then analyzed by the quadrupole mass spectrometer and the hydrogen content could be obtained through the integration of the hydrogen evolution curve.

2.3. Microstructural observation and mechanical evaluation

An optical microscope was used for microstructural characterization after standard grinding and polishing and etched in 3% nital solution. The as-quenched specimens were etched in saturated aqueous picric solution with some drops of surfactant to reveal austenite grain. The average austenite grain size was measured through the linear intercept method. A transmission electron microscope (TEM, Hitachi H-800) with energy dispersive X-ray spectrometer (EDS) was used to study precipitates. The operating voltage was 200 kV. Standard chromium trioxide-acetic acid solution was used for the preparation of thin foils in a twin-jet electropolishing apparatus. The volume fraction of austenite (V_v)

Download English Version:

<https://daneshyari.com/en/article/7975068>

Download Persian Version:

<https://daneshyari.com/article/7975068>

[Daneshyari.com](https://daneshyari.com)