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Effect of hydrogen on very high cycle fatigue behavior of a low-strength Cr-Ni-Mo-V steel containing micro-defects

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Abstract

The role of hydrogen in fatigue failure of low strength steels is not as well understood as of high strength steels in very high cycle fatigue regime. In this work, axially cyclic tests on a low strength Cr-Ni-Mo-V steel with charged hydrogen were carried out up to the very high cycle fatigue regime under ultrasonic frequency to examine the degradation of fatigue strength and associated failure mechanisms. Results show that the *S-N* curves show a continuously decreasing mode and hydrogen-charged specimens have lower fatigue strength and shorter fatigue lifetime, as compared with as-received specimens. It is concluded that the hydrogen trapped by inclusions drives interior micro-defects as dominant crack initiation site, and has a clear link to the initiation and early growth of interior fatigue cracks.

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Keywords: Low strength steel; Very high cycle fatigue; Non-metallic inclusion; Crack initiation; Hydrogen

1. Introduction

In many industries, the required design lifetime of key components often exceeds 10^7 cycles. A large number of research results have shown fatigue failure can occur beyond 10^7 cycles named as very high cycle fatigue (VHCF)

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regime. In this regime, fatigue crack is often initiated from interior inclusions or clusters of interior inclusions [Kuroshima et al. (1993); Abe et al. (1996); Kanazawa et al. (1997); Nakamura et al. (1998); Murakami et al. (1998); Yang et al. (2004)]. It is observed that there often exists a rough area in the vicinity of the critical inclusion, called granular bright facet (GBF) area in scanning electron microscopy (SEM) by Shiozawa et al. (2001) or optically dark area (ODA) in optical microscopy (OM) by [Murakami et al. (2002)]. The formation of ODA is associated with hydrogen in steels [Murakami et al. (2002)], and more than 90% of fatigue life was found to be spent in this zone [Shiozawa et al. (2006); Wang et al. (1999)]. The relationship between fatigue strength and inclusion size was proposed quantitatively by Murakami et al. (2002), and an empirical expression between fatigue strength and hydrogen concentration was developed by Li et al. (2009). It is known that the sensitivity of hydrogen is dependent on strength level of materials. What is unknown is, up to now, whether the ODA can be formed in low strength steels, especially in case of hydrogen environment. Therefore, in the present work, the effect of hydrogen on fatigue behavior of low-strength steels was discussed in the VHCF regime.

2. Materials and experimental method

The material tested was a low-strength Cr-Ni-Mo-V steel used as a steam turbine rotor material. A final tempering process was conducted at 560°C for 40 hours. The microstructures are mainly tempered martensites [Zhu et al. (2015b)]. The chemical composition and the mechanical properties are listed in Tables 1 and 2, respectively. The specimen geometry for ultrasonic fatigue testing is shown in Fig. 1. To reduce the influence of surface roughness as much as possible, all specimens were mechanically polished. The final surface roughness of specimen, R_a, is less than 0.2μm.

The hydrogen charging technique employed here was cathodic charging. The solution used was an aqueous solution of 0.25mol/L NaOH, at a current density of 1mA/cm^2 for over 48 hours. After cathodic charging, the specimens were coated with cadmium to prevent hydrogen desorption, and then placed at ambient temperature for 12 hours to homogenize the hydrogen distribution.

Ultrasonic fatigue tests were performed at approximately 20 kHz using an ultrasonic fatigue machine (USF-2000, Shimadzu, Japan). A sine type cyclic load with a load ratio of −1 was applied. During the tests, compressive air was used during fatigue testing to reduce "self-heating" of specimens. In addition, an intermittent loading scheme, i.e., 500 ms of pulse followed by 1000 ms of pause, was employed to minimize the thermal effect. The fatigue tests terminated until the fatigue cycles reached 10^9 cycles. Fracture surfaces of all failed specimens were examined with the help of optical microscopy (OM) and scanning electron microscopy (SEM) for crack initiation analysis.

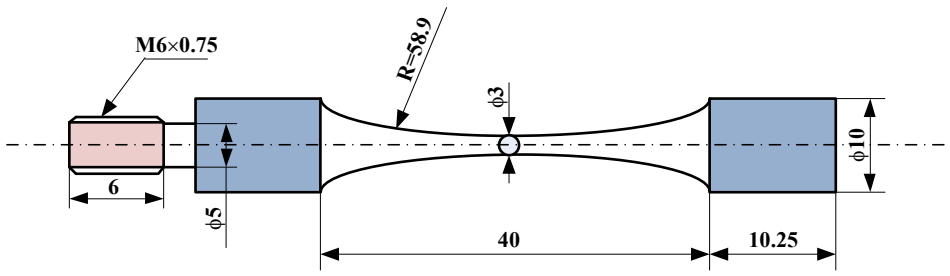

Fig. 1 Shape and dimensions of VHCF specimen machined from the 25Cr2Ni2MoV steels for testing at ultrasonic frequency

Table 1. The chemical composition (wt %) for the 25Cr2Ni2MoV steel.

C	Mn	Si	Ni	V	Cr	Mo	P	S	Cu	Fe
0.18–0.27	0.12–0.28	0.12max	2.05–2.35	0.12max	2.15–2.45	0.63–0.82	0.015max	0.015max	0.17max	balance