Materials Science and Engineering A 395 (2005) 141–147

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Evaluation of material degradation of 1Cr–1Mo–0.25V steel by non-destructive method

Chang-Sung Seok*, Jae-Mean Koo

School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-gu, Suwon, Kyonggi-do 440-746, Republic of Korea

Received 27 August 2004; received in revised form 4 December 2004; accepted 6 December 2004

Abstract

In this study, specimens with several different degradation levels were prepared by isothermal aging heat treatment at 630 °C for evaluating material degradation of 1Cr–1Mo–0.25V. The results from tensile and fracture tests were compared with those from BI tests, the dc potential drop and the ultrasonic method. These results show that normalized Brinell hardness agrees well with normalized tensile strength at the viewpoint of material degradation. It also shows the tensile strength and fracture toughness of degraded material can be determined by Brinell hardness, resistivity and the attenuation coefficient by the ultrasonic method.

Keywords: Ball indentation; Degradation; Fracture toughness; 1Cr–1Mo–0.25V; dc potential drop method; Ultrasonic method

1. Introduction

Low-alloy ferrite steel, 1Cr–1Mo–0.25V, is widely used as a material for high temperature structural components in electric power generation industries. However, as its mechanical properties are degraded easily in long-term service at high temperatures, it is necessary to estimate the degree of degradation in order to assure the safety in service.

Destructive methods are reliable to the evaluation of material degradation, but there is a difficulty in extracting specimens from industrial facilities in service. Therefore the evaluation of material degradation by non-destructive methods such as the ball indentation technique, the electric resistance tests and the ultrasonic tests is required.

The ball indentation (BI) tests [1,2] have the potential to assess the mechanical and fracture properties non-destructively and replace conventional fracture tests. These tests were shown to yield σ–ε curves that correlated well with the standard destructive tensile tests.

One non-destructive method widely used is the dc potential drop method. It is based on the fact that the resistivity is sensitive to not only the variation of macroscopic structure, but also to the microstructure due to material degradation. The four-point probe has been proven to be a convenient method for measuring resistivity [3].

The ultrasonic method is a good technique to evaluate the mechanical properties. Velocity and attenuation of ultrasonic are two important parameters in linear ultrasonic technique. The attenuation of ultrasonic is sensitive to the grain size of material and its frequency. The velocity of ultrasonic is a function of its frequency or wavelength and when propagated in a medium it is dispersive [4,5]. The ultrasonic methods used for flaw detection are based on observing the waves reflected or scattered by flaws such as porosities, cracks and dislocations.

In this study, test materials with several different degradation levels were prepared by isothermal aging heat treatment at 630 °C. The effects of aging on the mechanical properties of each specimen were investigated by tensile and fracture toughness test. Those tests were compared with BI tests, the dc potential drop method and ultrasonic method.

2. Aging materials and destructive tests

The chemical composition of low-alloy ferritic steel, 1Cr–1Mo–0.25V is given in Table 1. In this study, the ag-

* Corresponding author.
E-mail address: kjm9000@hanmail.net (J.M. Koo).

0921-5093/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2004.12.024

Table 1
Chemical composition (wt.%) of 1Cr–1Mo–0.25V

C	0.29
Si	0.01
Mn	0.74
S	0.004
P	0.007
Ni	0.060
Cr	1.29
Mo	1.24
V	0.25
Sn	0.0047

ing materials were prepared to simulate the field conditions by the accelerating aging method. The temperature of aging was selected at 630 °C, which is higher than around 538 °C, in-service temperature in the operating conditions. Degradation time was determined from the self-diffusion theory of Fe by Eqs. (1) and (2). The D_1 and D_2 of the equations are diffusion coefficients for each 538 and 630 °C and the degradation time (t_2) for 630 °C is followed as Eq. (3) [6]

$$D_1 = D_0 \exp\left[-\frac{Q}{RT_1}\right] = \frac{C}{t_1} \quad (1)$$

$$D_2 = D_0 \exp\left[-\frac{Q}{RT_2}\right] = \frac{C}{t_2} \quad (2)$$

$$t_2 = t_1 \exp\left[\frac{Q}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] \quad (3)$$

where R is the gas constant (8.314 J/mol K) and Q is the activation energy (65 kcal/mol) for the self-diffusion of Fe. T_1 and T_2 are degradation temperature while t_1 and t_2 are degradation time. These equations are based on the assumptions that the material degrades at the two different temperatures by the same structural change. There is a limit to the use of these because in the case for the degradation of 1Cr–1Mo–0.25V the microstructure would change not only by carbide coarsening but also by grain growth and carbide spherioidization. In the case of X20CrMoV12.1 alloy steel pipe, there is a report that microstructural observation shows that the carbides in the exposed pipe coarsened heavily with enriching alloying elements of Cr and Mo from the matrix during long-term service exposure, so the coarsened carbides reduce both precipitation and solid solution strengthening mechanisms and the degradation of the material is mainly related to carbide coarsening [7]. Several researchers have applied these to the accelerating aging process of 1Cr–1Mo–0.25V alloy steel because it is difficult to sample the aged material on site [8,9]. In this study, aging was carried out for four different aging times: 0, 453, 933 and 1820 h at 630 °C. The aging time at 630 °C for equivalent microstructure served at 538 °C are given in Table 2.

Microstructure of the virgin and degraded materials was characterized using an optical microscope. Fig. 1 shows the microstructure of the material for each degradation time. Carbide coarsened more heavily with precipitation at the grain boundaries with increasing aging time. These changes of microstructure with increase of aging time were expected to decrease in strength.

Table 2
Aging time at 630 °C for equivalent microstructure serviced at 538 °C

Aging time at 538 °C (h)	0	27653	56950	111104
Aging time at 630 °C (h)	0	453	933	1820

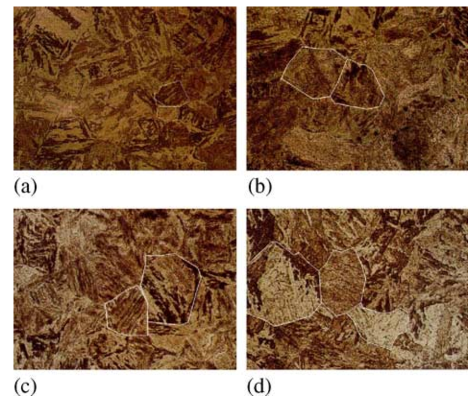

Fig. 1. Microstructure (400×) for each material after aging for (a) 0 h, (b) 453 h, (c) 933 h and (d) 1820 h at 630 °C.

Tensile tests were performed according to ASTM E8-95 using a universal test machine at room temperature. Fig. 2 shows the effect of aging time on σ–ε curves from these results. We note that with increasing aging time, strength decreased and ductility increased.

The fracture toughness (K_{IC}) test was carried out using a 25 tonnes hydraulic dynamic tester according to ASTM E 399-90. CT type specimens of 25.4 mm thick were used. But because the tests did not satisfy the size requirements for a valid K_{IC}, the results of toughness tests were transcribed as K_Q (Table 3).

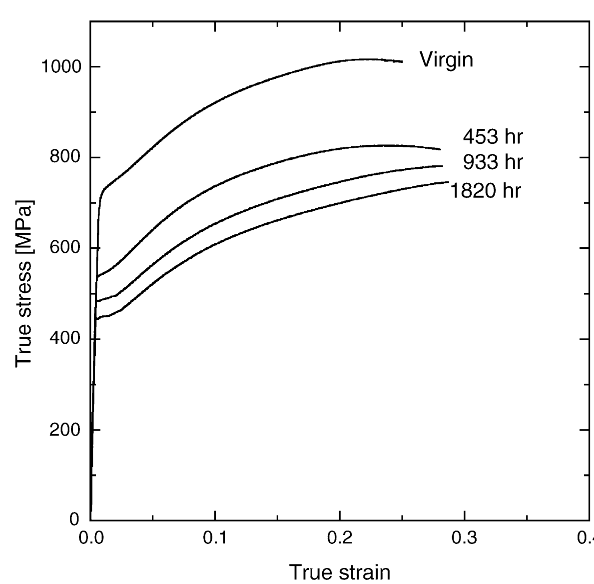

Fig. 2. The effect of aging time on σ–ε curves.