Journal of Alloys and Compounds 645 (2015) S460–S463

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jalcom

Application of acoustic emission method for investigation of hydrogen embrittlement mechanism in the low-carbon steel

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ARTICLE INFO

Article history:
Available online 25 December 2014

Keywords:
Hydrogen embrittlement
Fractography
Acoustic emission
Fisheye
Quasi-cleavage

ABSTRACT

The hydrogen embrittlement (HE) phenomenon in the electrolytically charged mild low-carbon steel was investigated during tensile testing coupled with in situ acoustic emission (AE) measurements and post mortem fractographic analysis. It was demonstrated that the ductility reduction correlated with the formation of HE-induced quasi-cleavage regions known as “fisheyes” which formed during the necking stage under the influence of mobile hydrogen. Based on the AE analysis we conclude that formation of “fisheyes” in the mild steel under load cannot be explained by a decohesion mechanism and the alternative mechanisms are discussed.

1. Introduction

Despite the long history of studies, hydrogen embrittlement (HE) of steels remains a topical and pressing problem. The nature of this phenomenon is still under discussion and thus identifying the underlying atomistic processes is still challenging because the microscopic mechanisms associated with HE are generally inferred from macroscopic property changes. The current opinions on existing HE theories have been comprehensively reviewed in [1]. Three major mechanisms have been proposed to account for the effect of hydrogen on embrittlement of a steel: (1) hydrogen-enhanced decohesion (HEDE), (2) hydrogen-enhanced localized plasticity (HELP), and (3) adsorption-induced dislocation emission (AIDE).

HEDE theory is based on the assumption that hydrogen reduces the interatomic cohesive forces in the metal lattice. Decohesion is usually envisaged as a collective separation of atoms when a critical crack-tip-opening displacement is reached. Commonly observed areas of featureless brittle fracture relief in the hydrogen charged steel specimens [2,3] are often provided as arguments in favor of this theory.

The HELP theory argues that embrittlement occurs due to the intensification and localization of plastic deformation under the action of hydrogen [4]. The crack is supposed to propagate due to localized plastic flow occurring along certain slip planes in the grain interior or at grain boundaries. On the macro level, the fracture surface exhibits generally brittle features, although some traces of plastic deformation can be distinguished on the cleavage facets [1]. Emphasizing the significance of dislocation-based mechanisms, the AIDE theory assumes that hydrogen adsorption on the crack surface reduces the surface energy and thus facilitates dislocation emission.

The objective of the present work is to clarify the mechanism of HE with an aid from the acoustic emission (AE) technique which has been proven extremely sensitive to the type of fracture and deformation mechanisms. Plastic deformation causes commonly a continuous low-amplitude noise type AE [5], while the formation of brittle cracks by the cleavage-like mechanism generates discrete pulses of high amplitude [6].

Most of AE studies performed so far have been focused on HE of a high strength, high-carbon or stainless steels [7–9]. In all these studies the discrete high-amplitude AE was found at various kinds of mechanical tests of hydrogen charged samples susceptible to intergranular type fracture. Reports concerning the application of the AE method to HE of mild low carbon steels demonstrating the transgranular brittle quasi-cleavage fracture relief are scarce [10].

2. Experimental

The commercial hot-rolled mild low-carbon steel S235JR with a chemical composition given in Table 1 was used in this study. Flat specimens with $15 \times 4 \times 2.5$ mm gauge dimensions were machined by an electric spark cutter and then mechanically and electrolytically polished. To get maximum ductility they were finally annealed in vacuum at 950 °C for 30 min.

Hydrogen charging was performed electrolytically in 5% sulfuric acid solution with 1 g/l $CS(NH_2)_2$ during 60 min. The resultant hydrogen concentration was varied by controlling the current density in the range of 10–300 mA/cm^2. The hydrogen content was determined in the Bruker Galileo G8 gas analyzer.

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http://dx.doi.org/10.1016/j.jallcom.2014.12.083
0925-8388/