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Measurement of hydrogen and embrittlement of high strength steels

J. Sanchez [a,*], S.F. Lee [a], M.A. Martin-Rengel [b], J. Fullea [a], C. Andrade [a], J. Ruiz-Hervías [b]

[a] Instituto de Ciencias de la Construcción "Eduardo Torroja", C/Serrano Galvache, 4, Madrid, Spain

[b] Departamento de Ciencia de Materiales de E.T.S.I. Caminos de la Universidad Politécnica de Madrid, C/Profesor Aranguren s/n, Madrid, Spain

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ABSTRACT

Hydrogen embrittlement of high strength steel is believed to be one of the main reasons for the cracking of prestressed concrete structures. In this study, hydrogen was generated on the steel surface by applying different fixed cathodic potentials. The steel was immersed in simulated carbonated concrete solutions with and without 0.1 M NaCl. Simultaneously, the steel was subjected to tensile loading at slow strain rate until fracture. Fractographic analysis and the measurement of the concentration of absorbed hydrogen in the iron lattice were performed. Results showed that the hydrogen atom only penetrated into the iron lattice when the steel was loaded above its yield stress. This phenomenon produced quasi-cleavage like fracture, and the strain at fracture was considerably reduced. The presence of chloride ion together with the hydrogen embrittlement did not provoke a remarkable synergic effect in the mechanical properties of high-strength steel.

1. Introduction

Concrete structures adopt active tendons that consist of pearlitic cold-drawn wires or strands in prestressed and post-tensioned structures. From the durability point of view, corrosion failures may occur by pitting or local corrosion due to the arrival of chlorides or the carbonation of concrete cover, causing a decrease in the local cross-section of the steel. Stress corrosion cracking together with hydrogen embrittlement have been also mentioned in many of the failures reported. However, the mechanisms of these two types of attacks have not been completely described yet. It is believed that hydrogen embrittlement could be one of the main reasons for the cracking of steel structures under stress [1–7]. The world estimated production of pearlitic-drawn wire is more than 25 million tons per year [8]. Pearlitic steels have a ferrite matrix with cementite lamellae. The ferritic phase is made of α-iron (body centred cubic lattice, bcc). To control and prevent the cracking of steel it is necessary to understand the chemical and physical properties of hydrogen inside bcc-iron. Hydrogen absorbed in iron has been studied from different approaches, both from a theoretical and experimental point of view. Unfortunately, a clear consensus about fundamental questions, like the nature of the equilibrium absorption site, the reasons for H to prefer some regions to others, or how to modify the diffusion barriers has not been reached. Fig. 1 shows the preferred absorption sites: the hydrogen is in the center of a tetrahedral and octahedral polyhedron with a Fe atom in each corner. Many theoretical papers have favoured hydrogen absorbed in the tetrahedral site (T-site) [9], some have preferred the octahedral one (O-site) [10], and others have reported that they are almost equivalent.

From experimental point of view, it is generally believed that tetrahedral sites are the most stable and hydrogen has low solubility and high mobility in bcc-iron. However, some experiments have achieved high solubility of hydrogen in iron using certain techniques [11–13] and they have concluded that hydrogen partly occupies the *O*-site, or have measured diffusion barriers

* Corresponding author.
E-mail address: javier.sanchez@csic.es (J. Sanchez).

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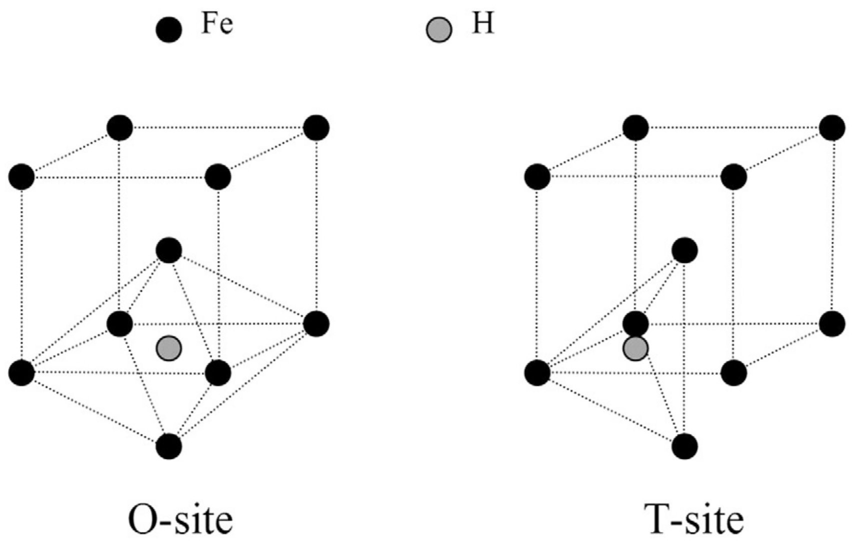

Fig. 1. High symmetry sites for H absorption inside α-iron: the octahedral (*O*) and tetrahedral (*T*) sites (grey) are shown along with iron atoms in the BCC lattice (black).

that depend on the amount of H admitted into the material [14]. There are several mechanisms that try to explain the effect of hydrogen into the iron lattice [15–17] and few experimental results about the behaviour of high strength steels under cathodic conditions [8,18–20].

The aim of this paper is to study the feasibility of hydrogen embrittlement of high strength steels in simulated carbonated and chloride contaminated concrete solutions under cathodic conditions and under different stress conditions [4,21]. The mechanical and fracture behaviours of high strength steel studied in this work are related to the diffused hydrogen concentration, cathodic potentials and the effect of the chloride ion. The amount of hydrogen that really incorporated into the steel has also been measured.

2. Methodology

2.1. Materials

Cold drawn high-strength steel supplied by EMESA (Arteixo, La Coruña, Spain) has been studied. It is an eutectoid steel and its chemical composition is 0.82% C, 0.65% Mn, 0.17% Si, <0.015% P, 0.022% S and 0.28% Cr. Fig. 2 shows the microstructure of the longitudinal and transverse cross sections. It can be seen that the ferrite/cementite lamellae are very thin and mainly aligned in the drawing direction, which coincides with the rod axis.

2.2. Equipment

Tests were performed with a universal test machine supplied by MICROTEST with a strain rate range between 49 mm/min and 0.001 mm/min. The load limit is 100 kN and the maximum displacement is 100 mm. An electrochemical cell has been adapted for working in the slow strain rate machine. The cell is sealed at its lower part by a gasket, whereas the upper part is not sealed hermetically to allow the displacement of the specimen. Some holes on the top of the cell enable to introduce a platinum counter-

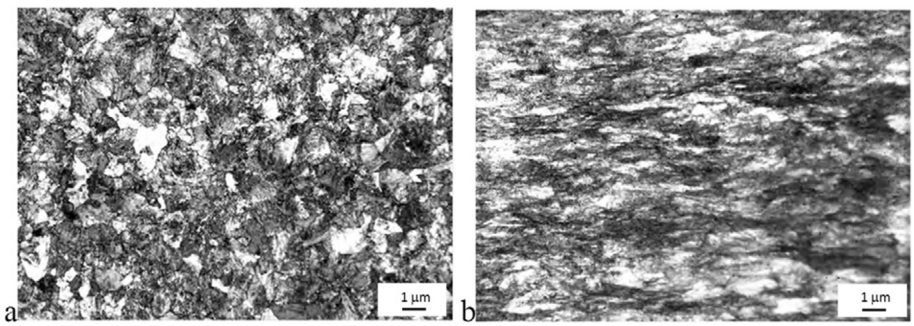

Fig. 2. Microstructure (×500 magnification) of cold drawn steel: (a) transverse and (b) longitudinal section.