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Failure mechanisms of high strength steels in bicarbonate solutions under anodic polarization

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Abstract

High strength steels used in prestressing concrete structures are not exempt from the effects induced by corrosion on the normal concrete reinforcement. Carbonation of surrounding concrete or mortar is not unlikely for prestressing tendons and strands. Moreover, these steels undergo to brittle fracture as a consequence of stress corrosion cracking phenomena. To evaluate if concrete carbonation can promote this kind of failure, constant load tests in bicarbonate aqueous solutions under anodic polarization were carried out on high strength steel wires. Microscopic examination pointed out that the wires exhibited a brittle fracture mode, while its natural feature is ductile, as indicated by air testing. Failure mechanism was evaluated by a fracture mechanic approach. Cracks initiation was attributed to an anodic dissolution mechanism, while its propagation, interpreted by means of the surface mobility theory, was related to interaction between hydrogen atoms and magnetite at a crack tip.

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1. Introduction

In prestressing concrete structures it is required the use of steels having high yield point, generally obtained by a cold drawing process, to ensure high performance of the concrete, also under severe load conditions. However, it has not been possible to

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exempt high strength steel from the same adverse effects induced by corrosion on the normal concrete reinforcement. For example, when the CO_2 , present in the atmosphere, comes in contact with concrete, it causes a neutralization of the alkaline components in the pore solution, reducing its pH. In this phenomenon, called carbonation, pH of the pores concrete solution reduces from values that allow the passivity of the steel, to the ones that induce the breakdown of the passive layer, so the corrosion mechanism is initiated. In such condition the final state of pore solution consists of a dilute aqueous solution of carbonates and bicarbonates [1].

To evaluate if the carbonation can promote brittle failure of tensioned steel, aqueous solutions containing HCO_3^- ions were used in electrochemical tests on prestressing steel [2]. According to the anodic dissolution mechanism [3], it was observed that stress corrosion cracking (SCC) could take place in a narrow potential range, situated at the active to passive transition, as result of competition between passive film growth and metal dissolution induced by the mechanical breakdown of the passive layer. This potential region was evaluated from polarization curves at fast and slow sweep rates, detecting the current density peaks. At a given potential, the steel could be susceptible to SCC if the peak corresponding to the fast sweep rate is higher than 1 mA/cm^2 . Moreover the ratio between the peaks intensities difference and the peak intensity at slow sweep polarization curve should be at least 1000. Thus it was found [2] that these conditions were fulfilled at an anodic region, close to -300 mV SCE . The peak found at this potential was explained with the formation of an oxide film, black coloured, identified as magnetite Fe_3O_4 , whose stability increased as the bicarbonate concentration decreased, as confirmed by the intensity of the peak.

The hypothesis was later confirmed by slow strain rate tests [4]. In these cases the fracture surface presented cleavage areas similar to the ones found at more cathodic potentials, where it was stated that the embrittlement was caused by hydrogen [5]. The conclusion was that cracks initiation took place by anodic dissolution, but cracks were helped to progress by hydrogen embrittlement in the anodic potentials region. Further tests indicated that the critical conditions are achieved using a 0.05 M NaHCO_3 solution at room temperature [6].

However it is not yet clear the hydrogen role in the mechanism, considering that the hydrogen ions reduction to adsorbed atoms, according to the following equation:



is not thermodynamically possible at the anodic potential range above mentioned for neutral solutions (i.e. at pH 8.3 the potential must be below than -730 mV SCE).

A possible explanation was proposed for different experimental conditions [7]. In fact by electrochemical tests, realized with notched stainless steel specimens in a NaCl 3\% solution, it was demonstrated that the reaction (1) at anodic potentials (-100 mV SHE , corresponding to -341 mV SCE) can take place because of a potential drop inside the crack, dependent on the partial pressure of molecular hydrogen in the solution. Nevertheless, the question is still opened.

Aim of the present work was to investigate if bicarbonate solutions under an anodic potential are aggressive also in constant load SCC tests, considering that slow

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