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Apparent fracture toughness of low-carbon steel CSN 411353 as related to stress corrosion cracks

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The occurrence of cracks in structural components indicates a certain threat to their reliable operation, because these cracks can grow during operation and reach critical sizes, leading to fracture. The fracture resistance of a structural component is given by the fracture toughness of the material, determined on standardized specimens with a precycled fatigue crack, and the constraint. The fracture toughness itself depends also on the environment. There is enough evidence that in the conditions of the environment assisted cracking the fracture toughness can be significantly reduced by hydrogen mechanism. Our research results have confirmed this and have demonstrated a considerable reduction in the stress corrosion fracture toughness as compared to that related to fatigue cracks. This should be taken into account when assessing the integrity of structural components with stress corrosion cracks. This paper presents experimental results concerned with the stress corrosion fracture toughness of specimens from a DN150 gas line pipe made of low-C steel CSN 411353.

1. Introduction

Stress corrosion cracking (SCC) is the most insidious type of damage to structures such as high-pressure pipelines, pressure vessels and storage tanks [1]. A good comprehensive survey of the basic concepts of this type of damage is given in the paper of Woodtli and Kieselbach [2]. The insidiousness of stress corrosion cracking lies in the fact that it often occurs without any visible deformation of the material and is very hard to be identified, i.e. timely diagnostics is very difficult [3]. It can therefore lead to unexpected fractures. SCC may occur by several mechanisms; one of them is the hydrogen mechanism leading to hydrogen embrittlement (HE). In the HE process hydrogen atoms from the environment enter the metal and diffuse in the lattice. They tend to be attracted to regions of high triaxial tensile stress where the metal structure is dilated. Thus, the hydrogen atoms are drawn to the regions ahead of crack tips or sharp notches that are under stress. They can occupy the interstitial sites in the metal lattice, as shown by neutron diffraction in many cases [4], and dilate thus the crystal lattice. Hydrogen atoms can also be trapped by dislocations and can influence their mobility [5]. It is not quite clear what is the direction of this influence; it seems, however, that it is more likely that hydrogen atoms enhance rather than retard the motion of dislocations [6]. When H atoms are trapped by vacancies, impurities and/or grain boundaries there is enough space for the atoms to recombine to form molecules. These are more stable than are the arrangements of H atoms in the lattice but the internal pressure they are exerting in the traps generates sufficient stress to either to nucleate and propagate a crack [7] or to make the local region embrittled [8]. All these processes can lead to the reduction of ductility ahead of the crack tip reducing the fracture toughness of the material.

SCC pertains to environmentally assisted cracking (EAC). The concepts of linear elastic fracture mechanics are commonly used in SCC to determine the susceptibility of engineering materials to SCC in various environments. The studies are mostly directed at determining the threshold value K_{ISCC}, below which the SCC would not occur [9] or at determining the crack growth kinetics curves as a fundamental tool for design against SCC [10,11]. Elastic plastic fracture mechanics concepts are used in stress corrosion crack growth by employing the J integral as a fracture parameter to determine the onset of crack growth (J_{Ic}) and the J-based R curve (J–Δa) [12]. A number of different testing methods are used for studying the SCC processes. They usually utilize a procedure that standard specimens are exposed to a corrosive environment and at the same time they are subjected to mechanical loading [13]. The R curves for a specific material in a certain environment are customarily obtained by the partial unloading method at moderate displacement rates or by the D.C. potential drop method preferably

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