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Effect of Heat Treatment on Hydrogen Diffusion Behavior of Process Pipe Steel

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The influence of heat treatment on the HIC susceptibility in process pipe steel was investigated with respect to the hydrogen diffusion behavior by employing the electrochemical permeation technique. This study clearly shows that, contrary to other microstructures, in acicular ferrite, iron carbide (Fe_3C) particles are newly precipitated mostly along the grain boundaries by the simulated PWHT conducted at 620°C for one hour. In addition, a decrease in hydrogen diffusivity attributed to the hydrogen trapping effect by the Fe_3C leads to an increase in apparent solubility. As a result, heat-treated process pipe steel is more susceptible to HIC.

INTRODUCTION

The process pipe steels used in the petrochemical industry suffer frequently from hydrogen-induced cracking (HIC) failures when they are used in a sour environment (Bruno et al., 1999). With the depletion of high quality oil and gas, the HIC becomes severe since low-quality oil and gas contain large amounts of H_2S, which is the major source of diffusible hydrogen in the steel. The atomic hydrogen, which is reduced from H^+ ion dissociated from H_2S, tries to become a hydrogen molecule by the recombination reaction ($H + H \rightarrow H_2$). In the presence of H_2S, however, the recombination reaction is suppressed, and the hydrogen atoms are easily diffused into the steel matrix. The diffusible hydrogen atoms are trapped at various metallurgical defects in the steel such as grain boundaries, dislocations, and interfaces between the steel matrix and nonmetallic inclusions. As a result, HIC failures can occur (NACE MR0175, 1993).

HIC failures in the steel have been reduced greatly by applying advanced steel-making technology. Especially, proper procedures of Ca-treatment for inclusion shape control have proved to increase HIC resistance (Cicutti et al., 1997; Domizzi et al., 2001). In addition, numerous efforts have been made to develop sour-resistant steel with optimal microstructures by employing various heat treatment processes. A considerable body of literature has reported the relationship between microstructures obtained by the different heat treatment conditions and HIC resistance in the sour environment (Koh et al., 2004; Park et al., 2008; Torres-Islas et al., 2008; Beidokhti et al., 2009). It has been generally accepted that heat treatment such as tempering and post-weld heat treatment (PWHT) conducted normally at 500°C–600°C has a beneficial effect on subsequent HIC resistance in a sour environment (Kim et al., 2008; Robertson and Thompson, 1980; Serna et al., 2005; Carneiro et al., 2003). Particularly, Luppo and Ovejero-Garcia (1991) and Tau et al. (1996) have reported that the tempering treatment conducted to toughen the low-temperature transformation microstructure, such as martensite and bainite, improves HIC resistance due mainly to reduction in dislocation density, hardness, and residual stress. Furthermore, Kim et al. (2011) have investigated the influence of PWHT conducted at 620°C on hydrogen diffusion and HIC behavior in the pressure vessel steel by means of the electrochemical permeation technique. They indicated that the heat treatment can be effective in reducing the HIC susceptibility of the steel. This is closely related with the agglomeration of fine carbide particles (Fe_3C) to coarse-sized particles during the heat treatment. It leads to a decrease in the total interfacial area of ferrite/Fe_3C acting as a reversible trapping site for hydrogen atoms, resulting in low apparent hydrogen solubility in the steel. These phenomena can be identified in a variety of microstructures of the steel ranging from ferrite/pearlite to bainite (Luppo and Ovejero-Garcia, 1991; Radhakrishnan and Shreir, 1967; Parvathavarthini et al., 2001). However, a recent study conducted by the present authors has indicated an opposite phenomenon in the process pipe steel containing acicular ferrite; the study revealed that heat treatment conducted at 620°C for one hour on the pipe steel leads to an increase in diffusible hydrogen content in the steel that makes it more prone to HIC (Kim et al., 2012).

It is frequently required for process pipe steel to undergo PWHT at 620°C on welded areas to relieve residual stress after the

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KEY WORDS: Process pipe steel, sour environment, PWHT, acicular ferrite, Fe_3C precipitate, hydrogen permeation, HIC.