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The effects of sulfide stress cracking on the mechanical properties and intergranular cracking of P110 casing steel in sour environments

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Abstract: Variation and degradation of P-110 casing steel mechanical properties, due to sulfide stress cracking (SSC) in sour environments, was investigated using tensile and impact tests. These tests were carried out on specimens, which were pretreated under the following conditions for 168 hours: temperature, 60 °C; pressure, 10 MPa; H_2S partial pressure, 1 MPa and CO_2 partial pressure, 1 MPa; preload stress, 80% of the yield strength (σ_s); medium, simulated formation water. The reduction in tensile and impact strengths for P-110 casing specimens in corrosive environments were 28% and 54%, respectively. The surface morphology analysis indicated that surface damage and uniform plastic deformation occurred as a result of strain aging. Impact toughness of the casing decreased significantly and intergranular cracking occurred when specimens were maintained at a high stress level of 85% σ_s.

Key words: Acidic solutions, high-temperature corrosion, hydrogen embrittlement, intergranular corrosion, sulfide stress cracking

1 Introduction

Steels react with hydrogen sulfide, forming metal sulfides and atomic hydrogen as corrosion byproducts. The atomic hydrogen can diffuse into the metal matrix, creating hydrogen embrittlement and subsequent cracking. This is termed sulfide stress cracking (SSC) and is more severe at low pH values.

Sulfide stress cracking is becoming a key issue due to high levels of H_2S and CO_2 in new natural gas reservoirs (Carneiro et al, 2003; Kermani et al, 2006).

Furthermore, severe working conditions, to which drilling equipment is exposed in reservoirs, require high grade steels capable of resisting SSC and withstanding high mechanical loads under conditions that encourage hydrogen embrittlement (HE) (Zhao and Yang, 2003; Zhao et al, 2003; Crabtree and Gavin, 2005).

Therefore, it is essential to evaluate different methods for the determination of the ability of a material to resist cracking in sour environments (Grabtree and Gavin, 2005). The National Association of Corrosion Engineers, NACE International, adopts different methods for evaluating a material's susceptibility to stress corrosion cracking (SCC) in a wet H_2S environment. Sulfide stress cracking (SSC) is a form of hydrogen embrittlement which is a cathodic cracking mechanism. It should not be confused with the term stress corrosion cracking (SCC) which is an anodic cracking mechanism.

Specifically, testing methods using the bend specimen geometry described in the ASTM standards (ASTM International, 1999) and the double cantilever beam (DCB) test described in the NACE standards (NACE International, 2005) are used in design/fitness for service evaluating and for determining material qualifications and specifications (Hay, 2001; Cravero et al, 2009). Gelder et al (1987) investigated the susceptibility of stainless steel to SSC in sour environments containing H_2S, CO_2 and chloride using slow strain rate testing (SSRT). Albarran et al (1999) studied the effects of heat-treatments on pipeline steel resistant to SSC, using linear elastic fracture mechanics (LEFM) on standard impact specimens. Several researchers (Ritchie et al, 1978; Toribio et al, 1993; Thompson et al, 2007) investigated the main variables that affect SSC of steel in sour environments. Although the DCB test is standardized, it is widely known that using the NACE TM0177 method D (DCB test) testing procedure can affect the value obtained for the fracture toughness (K_{IC}). In this procedure, variables such as the height of the wedge (the initially applied K_I) and the pH of the solution can also affect the final results (Mack et al, 2000; Cravero et al, 2010).

There is an urgent need to develop better methods for evaluating the mechanical properties of metals after exposure to aqueous H_2S/CO_2 environments with high H_2S partial

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