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Effect of H_2S/CO_2 partial pressure ratio on the tensile properties of X80 pipeline steel

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ABSTRACT

Tensile properties and fracture behavior of X80 pipeline steel exposed to corrosion environments with different H_2S/CO_2 partial pressure ratios were investigated through slow strain rate tests (SSRT). The results show that the tensile properties of X80 steel were damaged in H_2S/CO_2 environments. The tensile strength and elongation to failure of X80 steel decreased significantly with increasing H_2S/CO_2 partial pressure ratio. The fracture appearance of the corroded samples exhibited mixed ductile–brittle rupture. Fractured areas with quasi-cleavage features increased as H_2S/CO_2 partial pressure ratio increased. Different types of secondary cracks can be identified on the SSRT specimens in the corrosion environments with different H_2S/CO_2 partial pressure ratios.

Introduction

Gas and oil energy is an important sector of the global economy, even as the social and economic bases in certain countries. For years, with the growing demand of oil and gas in a low-cost and safe way, development of high-strength steel pipelines has savings in the total cost of long-distance oil/gas transmission significantly. With rapid development in the oil and gas industry, there is a serious problem in the mining and transportation process which caused by the existence of corrosive mediums (e.g., Cl^-, S^{2-}, CO_2, and H_2S). Steel could suffer pitting, localized corrosion and hydrogen embrittlement in the strong corrosive environments [1–4]. H_2S, which has highly corrosive and toxicity, can lead to fracture failure of oil and gas equipment. Besides uniform and localized corrosion, wet H_2S could cause hydrogen-induced cracking (HIC) and stress corrosion cracking (SCC), especially for high-strength steel. The transportation of oil and gas containing H_2S gas has been a thorny issue [5–8]. The fracture failure of pipeline under an H_2S/CO_2 environment threatens the safety of oil and gas transportation.

Over the past few decades, numerous researchers have studied the H_2S/CO_2 corrosion. According to Pots [9], when the H_2S/CO_2 partial pressure ratio is more than 500, CO_2 controls the corrosion and $FeCO_3$ is the corrosion product; whereas

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when the H_2S/CO_2 partial pressure ratio is less than 20, H_2S is the main factor and FeS is the corrosion product. Papavinasam [10] stated that when the H_2S concentration is lower than that of Fe^{2+}, the corrosion products are controlled by FeS and $FeCO_3$; otherwise, it is controlled by FeS [11–15]. Many studies also demonstrated the mechanism of H_2S/CO_2 corrosion of pipeline and presented certain models [16–20]. Though H_2S/CO_2 corrosion of pipelines has been studied widely, most of the studies focused on the characteristics of corrosion products and weight loss test after immersion. The corrosion mechanism of steel under H_2S/CO_2 conditions remains poor, especially in the environments with high H_2S partial pressure. In addition, no clear description is available on the effects of different H_2S/CO_2 partial pressure ratios on the mechanical properties of pipeline steel.

Based on the aforementioned insights, this study evaluates the effect of H_2S/CO_2 partial pressure ratio on the mechanical properties of X80 pipeline steel. The fracture morphology and corrosion products are examined using SEM-energy dispersive X-ray spectroscopy (SEM-EDS). Meanwhile, this study is of great interest to the oil and gas industry.

Experimental procedure

Materials and sample preparation

The material used in this study was X80 pipeline steel with a chemical composition (wt.%): C 0.055, Si 0.2002, Mn 1.3917, S 0.0019, P 0.0017, Cr 0.3184, Mo 0.3184, Ni 0.2636, Al 0.0173, and Fe balance. The specimens were machined according to the requirements of slow strain rate tensile test (SSRT) machine in the American Monitoring Analysis of Thermoelectric Technology Company [21]. For microstructural observations, some specimens were ground with 2000 grit carbide silicon paper and polished with 1.2 μm diamond pastes. They were then degreased with acetone and etched with a mixture of 5% nitric acid and ethanol. The steel microstructures were characterized using an optical microscope (OM).

Slow strain rate tensile tests (SSRT)

Slow strain rate tensile tests (SSRT) were conducted in an autoclave filled with a test solution at a strain rate of 6×10^{-6} s^{-1} on a slow strain rate test system (CORTEST Company) at room temperature. The solution consisted of 5.0 wt.% sodium chloride dissolved in distilled water. Before the experiments, the specimens were rinsed with deionized water and degreased with acetone.

In order to investigate the effect of H_2S/CO_2 partial pressure ratio on the tensile properties of X80 pipeline steel, the pressure was controlled by changing the amounts of H_2S and CO_2. The CO_2 partial pressure was maintained at 0.5 MPa. The amounts of H_2S were changed to obtain the environments with different H_2S/CO_2 partial pressure ratio (0.5:1, 1:1, 2:1 and 3:1). The index of SCC susceptibility of the specimens in different corrosion environments was determined by the relative tensile loss I_σ and the relative plasticity loss I_δ, which can be expressed as follows:

$$I_\sigma(\%) = \frac{\sigma_0 - \sigma_H}{\sigma_0} \times 100\% \quad (1)$$

$$I_\delta(\%) = \frac{\delta_0 - \delta_H}{\delta_0} \times 100\% \quad (2)$$

where σ_0 and δ_0 are the ultimate tensile strength and elongation to failure in the as-received state (without corrosion), respectively; and σ_H and δ_H are the ultimate tensile strength and elongation to failure after corrosion, respectively. After the tensile tests, the fracture surfaces of the specimens were subjected to a detailed analysis by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

Morphological characterization of fracture and corrosion products

The morphological characterization of fracture and corrosion products were characterized by SEM (FEI Quanta 200F) under the following scanning parameters: 200–300 kV, 25 × –200 × magnification, 1 nm resolution, and high vacuum scanning mode. Energy dispersive X-ray spectroscopy (EDS) analysis was performed with a SEM coupled with a Trident XM4 type spectrometer.

Results

SSRT tests

Fig. 1 shows the stress–strain curves of X80 steel in the corrosion environments with different H_2S/CO_2 partial pressure ratio. Different stress–strain behaviors of steel were observed in the H_2S/CO_2 environments. The blank specimen was measured in 0.1 MPa N_2 at room temperature. When tested in N_2, a clear yield phenomenon and plastic deformation stage appeared in the stress–strain curve. The plastic deformation stage decreased with the continuous increase in the H_2S/CO_2 partial pressure ratio. When the H_2S/CO_2 partial

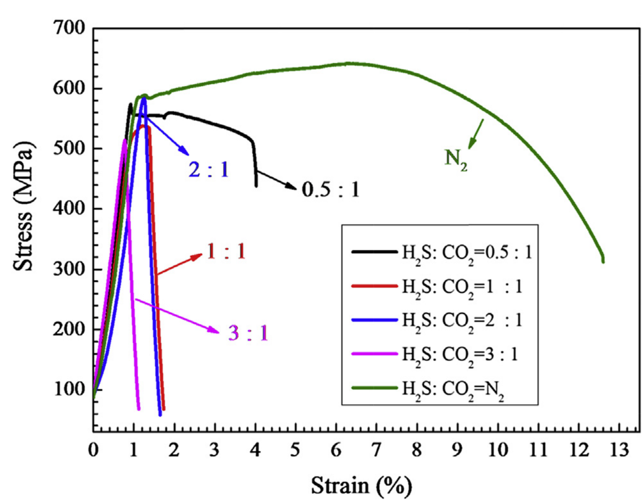

Fig. 1 – Stress-strain curves of X80 steel in the corrosion environments containing different partial pressure ratios of H_2S/CO_2.

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