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Synergistic effect of stress and crevice on the corrosion of N80 carbon steel in the CO_2-saturated NaCl solution containing acetic acid

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ABSTRACT

The corrosion behaviour of N80 carbon steel under the coexistence of stress and crevice in the CO_2-saturated NaCl solution containing acetic acid (HAc) was studied by electrochemical measurements, surface analysis, and stress analysis. It is demonstrated that the corrosion potential of steel shifts negatively and corrosion activity is enhanced with increasing stress. A deep corrosion groove is formed at crevice mouth, which causes stress concentration, increasing the susceptibility to stress corrosion cracking (SCC). The stress concentration also results in larger driving force for crevice corrosion. Therefore, there is a synergistic effect of stress and crevice on the corrosion of steel.

1. Introduction

Downhole tubings are connected by casing collars through screw thread in the exploitation of oil and gas. However, the aggressive media inside the tubings can enter the crevice between the connected screw thread, and then cause crevice corrosion [1–3]. Meanwhile, the screw thread bears great stress produced by the weight of tubings, which could result in stress corrosion cracking (SCC) of the tubings [4–6]. Therefore, the coexistence of crevice and stress would cause serious corrosion of the screw thread in the tubings and casing collars.

In CO_2 environment, carbon steels would usually suffer from localised corrosion, especially in the corrosive media containing organic acids, such as acetic acid (HAc) [7,8]. Al-Jaroudi et al. [9] found that organic acids were responsible for the mesa attack of the joint of tubings. Amri et al. [10–12] investigated the effect of HAc on the pitting corrosion of carbon steel using an artificial pit. They revealed that the pitting corrosion was caused by the galvanic effect between the electrodes inside pitting hole and in the bulk solution due to the depletion of HAc and H_2CO_3 inside the pit. Some researchers [7,13,14] found that the presence of HAc prevented the formation of protective corrosion products and then contributed to triggering localised corrosion. Crevice corrosion is one of the most dangerous localised corrosions, which can result in localised defects on the metal surface in a relatively short time [15–17]. In our previous works [18,19], it was confirmed that the concentration of Cl^- and pH inside a crevice increased, and crevice corrosion of carbon steel was triggered by the galvanic effect between the two parts of the steel inside and outside crevice in the CO_2-saturated NaCl solution containing HAc. This crevice corrosion mechanism is different from the localized acidification mechanism for the pitting corrosion of steels in the neutral solution without deoxygenation [20,21], where the pH inside propagating pit decreases.

Some studies have shown that SCC is often initiated by localised corrosion defects [22–24]. Therefore, the localised defects resulting from crevice corrosion could be as the sources for crack initiation, increasing the susceptibility of SCC. Turnbull et al. [25,26] confirmed that SCC could be initiated from pits in the chloride containing solution and a model was developed to predict the relationship between the mean crack growth rate and the percentage of pit-to-crack transition. Horner et al. [27] found that the preferential site for crack initiation was on the pit wall, and the cracks on the pit wall could propagate around the pit and coalesce to form a through crack. Zhu et al. [28] studied the relationship between pitting corrosion and the early-stage of SCC under ultra-low elastic load by finite element analysis. They found that stress and strain concentration appeared at the shoulder of pit.

In fact, stress could also influence the localised corrosion behaviour of metals. It was reported that the applied stress could increase the concentration of donors and acceptors in passive film and then enhance the localised corrosion susceptibility of steel [29,30]. The non-uniform distribution of elastic stress on the metal could cause galvanic corrosion and contribute to initiating localised corrosion [31]. Guan et al. [32] found that cyclic stress with a stress peak above yield strength could significantly promote the pitting corrosion of 304 stainless steel.

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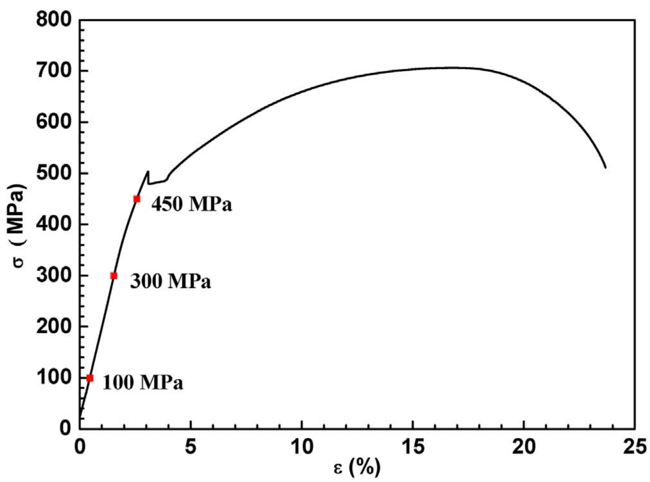

Fig. 1. Stress (σ)-strain (ε) curve of N80 carbon steel in the air.

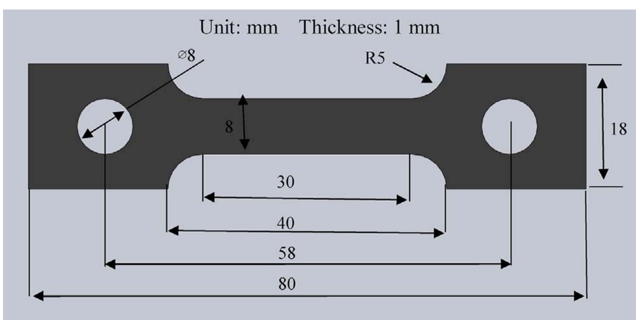

Fig. 2. Dimension of tensile specimen.

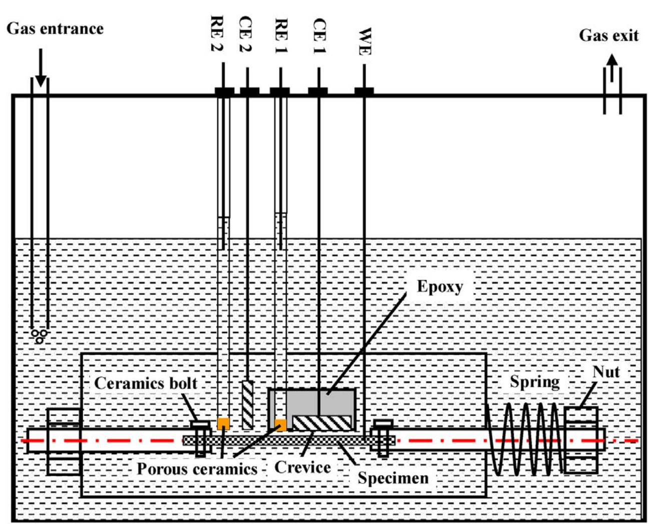

Fig. 3. Schematic diagram of experimental setup for electrochemical measurements under various stresses, or under both stress and crevice.

Although there are extensive studies on the crevice corrosion and SCC when only crevice or stress is present [33–36], there are few studies on the corrosion of steel under the coexistence of crevice and stress. It is not clear if there is interaction between crevice and stress on the corrosion of steel. In this study, the corrosion of N80 carbon steel under the coexistence of tensile stress and crevice in the CO_2-saturated NaCl solution containing HAc was studied by electrochemical measurements and surface analysis. This work could provide the insight on the interaction of tensile stress and crevice on the corrosion of N80 carbon steel.

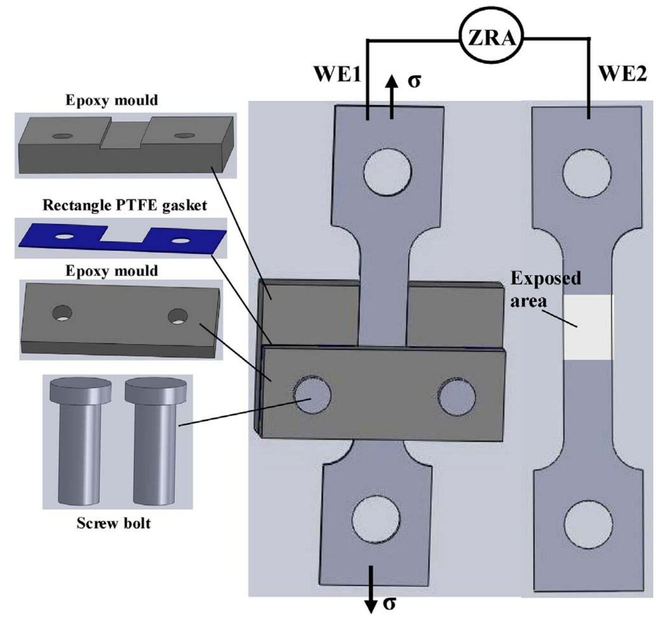

Fig. 4. Schematic diagram of galvanic current measurement between the specimen with crevice and/or stress (WE1) and the specimen without crevice and stress (WE2).

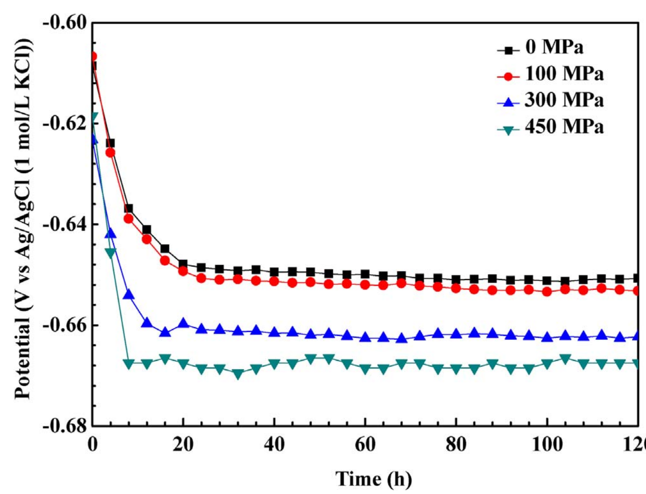

Fig. 5. Time dependence of the open circuit potential of N80 carbon steel under different stresses (without crevice) in the CO_2-saturated 1.65 wt% NaCl solution containing 600 mg/L HAc.

2. Experimental

2.1. Material and solution

In this experiment, API N80 carbon steel was used as material. Its chemical composition (wt.%) contained: 0.42% C, 0.24% Si, 1.55% Mn, 0.012% P, 0.004% S, 0.051% Cr, 0.18% Mo, 0.005% Ni, 0.01% Ti, 0.06% Cu, and Fe balance. Fig. 1 shows the measured stress-strain curve of N80 carbon steel. The tensile strength and yield strength were 706.4 MPa and 479.2 MPa, respectively. Planar tensile specimen, as shown in Fig. 2, was machined as per standard GB/T 15970. The specimen was coated with insulating varnish except the exposed area (0.8 cm^2 or 1.6 cm^2) in gauge section. Before testing, all the specimens were abraded with 800 grit silicon carbide paper, and then degreased with acetone and cleaned with distilled water.

The test solution was 1.65 wt% NaCl solution containing 600 mg/L HAc, which was prepared from analytical grade reagents and deionized water. The test solution used in this experiment was as per the Cl^- ions concentration (about 10000 mg/L) in the formation water of an oil