



# Observation of the pitting corrosion and uniform corrosion for X80 steel in 3.5 wt.% NaCl solutions using *in-situ* and 3-D measuring microscope



Yafei Wang, Guangxu Cheng\*, Yun Li

School of Chemical Engineering and Technology, Xi'an Jiaotong University, Xi'an 710049, China

## ARTICLE INFO

### Article history:

Received 11 January 2016

Received in revised form 19 April 2016

Accepted 26 May 2016

Available online 27 May 2016

### Keywords:

A. Steel

B. SEM

*in-situ* microscope

C. Pitting corrosion

## ABSTRACT

The corrosion morphology of X80 steel in neutral NaCl solutions was investigated using an *in situ* 3-D measuring microscope. The time-evolutions of the initiation and propagation process of corrosion pits are presented and the three-dimensional structure of the corrosion pits could be observed. Both regular corrosion pits and corrosion products of this uniform corrosion could be analyzed. Furthermore, the effect of temperature on the corrosion morphology was studied. The mechanisms related to the initiation and propagation processes of pitting corrosion as well as the effect of temperature for X80 in NaCl solutions have been proposed.

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## 1. Introduction

High strength steels have been widely used around the globe for the construction of long-distance oil and gas pipelines. By 2012, the total length of X80 pipelines in China has exceeded 4000 km [1]. The use of high strength steel in building pipelines with large volume and high pressure has reduced the pipeline construction costs significantly. However, depending on the age, these pipelines may suffer from both internal [2] and external corrosion processes [3–5] in onshore or offshore environments. Due to the special chemical composition of high strength pipeline steel, the corrosion behavior is potentially different from the corrosion behavior exhibited by other materials. Different and even controversial conclusions can be drawn by changing the material, even in similar environments. For example, it was found by Han [6] that the corrosion rate of J55 steel in CO<sub>2</sub>-saturated brines decreases steadily with increasing chloride concentration. However, Eliyan [7] reported a “threshold phenomenon” of the chloride effect for X100 high strength steel under similar conditions.

In our previous work, the effect of the pH and chloride on the pitting behavior of X80 steel in NaCl solutions was investigated and featured a regular pitting morphology in neutral chloride solutions [8]. To investigate this regular pitting morphology, an image recog-

nitiation method has been introduced to study the distribution of the pit sizes together with the spatial point pattern [9]. The results obtained from the image-recognition-based statistical analysis of high strength pipeline steel in aerated NaCl solutions indicate that the pit diameter follows a lognormal distribution and the pit sites prove to be completely spatial random [10]. The observed large pitting morphology was highly consistent with the results obtained by Yang et al. [11] for Ni-Cr-Mo-V steel in NaCl solutions under hydrostatic pressures; the morphology was also in accordance with the results obtained by Tsutsumi et al. [12] and Hustuty et al. [13] for stainless steel types in chloride solution. However, our results are very different from the pitting behavior of low carbon steel observed in unbuffered NaCl solutions [14]. Two different mechanisms have been proposed in an effort to explain the formation of near-circular large pits for Ni-Cr-Mo-V steel and stainless steel, respectively. Although the effect of pH, chloride and dissolved oxygen on the pitting behavior of X80 in chloride solutions has been discussed before in the literature [8], the mechanism of the large pitting morphology for X80 pipeline steel is not yet fully understood.

In this paper, an *in situ* optical microscope was used to observe initiation and propagation processes during pitting corrosion of X80 steel. The time-evolutions of the pit initiation and pit growth could be clearly captured and 3-D structures of the pits and corrosion products could be generated. Furthermore, the relationship between the inclusions and the initiation of pitting corrosion was investigated. On the basis of the microscopic observations, the

\* Corresponding author.

E-mail address: [gxcheng@mail.xjtu.edu.cn](mailto:gxcheng@mail.xjtu.edu.cn) (G. Cheng).

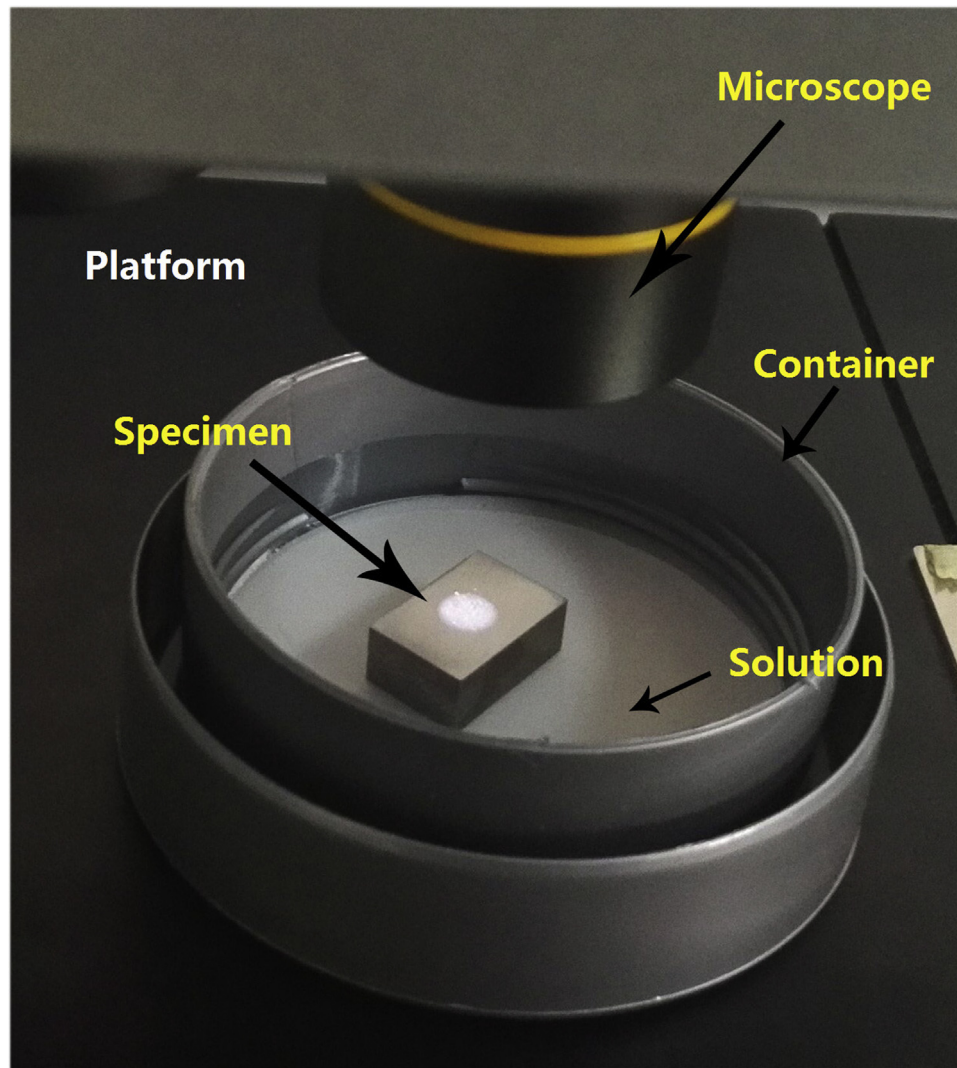


Fig. 1. Experimental setup for the *in situ* observations.

effect of temperature on the corrosion morphology could be studied. Finally, a mechanism for the observed corrosion morphology was proposed.

## 2. Experimental details

The specimens were cut from a X80 steel plate (15 mm thickness), exhibiting chemical compositions as follows (wt.%): C 0.07, Mn 1.77, Ni 0.22, Mo 0.21, Si 0.30, P 0.02, S 0.005, Cu 0.22 and Fe balance. The steel plate was provided by the China Special Equipment Inspection and Research Institute (CSEI). The stress-strain curve of the as-received high strength pipeline steel was obtained on a tensile machine, from which the yield strength and the tensile strength at room temperature were determined as 647.0 MPa and 772.8 MPa, respectively. Before immersion into the electrolyte, all specimens were ground with 400–2000-grit abrasive paper, polished with 1  $\mu\text{m}$  diamond paste, cleaned with distilled water and acetone, and finally dried in air. The specimens were subsequently immersed into a neutral 3.5 wt.% NaCl solution, which was prepared from analytical grade reagent and distilled water. For the *in situ* observations, the morphology was studied using an *in situ* optical microscope (Opto-digital DSX500, Olympus, Japan) at room temperature ( $18 \pm 1^\circ\text{C}$ ). The experimental setup is shown in Fig. 1. For the *ex situ* observations, all specimens were immersed in 3.5 wt.%

NaCl solutions at different temperatures ( $18 \pm 1^\circ\text{C}$ ,  $35 \pm 1^\circ\text{C}$  and  $65 \pm 1^\circ\text{C}$ ). After immersion, the specimens were removed from the electrolyte and dried in air. The 3-D measurements were carried out on a confocal laser scanning microscope (LEXT, OLS4000). Some of the specimens were also studied on a scanning electron microscope (SEM, Hitachi S-3000N) to confirm the corrosion morphology. The chemical compositions of the corrosion products and inclusions were characterized using energy-dispersive X-ray spectroscopy (EDX, JEOL, JSM-6390A). For comparison, the chemical compositions of the steel surfaces prior to the immersion tests were also confirmed using energy-dispersive X-ray spectroscopy (EDX, Hitachi SU8010).

## 3. Results and discussion

### 3.1. *In situ* observations

The time evolution of the pitting corrosion for X80 steel in 3.5 wt.% NaCl solutions at room temperature is shown in Fig. 2. From inspection of Fig. 2f it can be determined that a large amount of pits is formed on the surface after immersion for 30 min. Three pits, marked in Fig. 2f, were selected here to help discuss the initiation and propagation processes. The processes of pitting corrosion can

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