



Effect of Cr content on the corrosion performance of low-Cr alloy steel in a CO₂ environment



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ABSTRACT

Low-Cr alloy steel demonstrates lower corrosion rate than does C steel in a high-temperature and high-pressure CO₂-containing environment. This study aimed to clarify the role of the Cr content in mitigating corrosion and reports the performance of 1%Cr, 2%Cr, 3%Cr, 4%Cr, 5%Cr, and 6.5%Cr steels. The results show that low-Cr alloy steel in CO₂ at 80 °C and 0.8 MPa possesses spontaneous prepassivation characteristics when the Cr content is 3% or higher. Furthermore, the formation and peel-off of a prepassivation film on 3%Cr–6.5%Cr steels surfaces during polarization demonstrate that adequate amount of Cr in the steel substrate can cause protective layer. The main component of prepassivation film on 3%Cr steel is Cr(OH)₃. Thus, the role of Cr is revealed. An adequate amount of Cr in the steel substrate causes the formation of protective Cr(OH)₃ layer, which helps low-Cr steel to possess prepassivation characteristics. Prepassivation is the reason why low-Cr steel has a lower corrosion rate than C steel.

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1. Introduction

In the oil and gas industry, CO₂ in reservoirs generally causes severe corrosion of C steel in pipelines [1,2]. Adding Cr to C steel can enhance CO₂ corrosion performance at high temperatures and high pressures. Therefore, low-Cr alloy steel has gained considerable attention [3]. Many studies have conducted laboratory and field tests on 1%Cr, 3%Cr, 5%Cr, 7%Cr, and 9%Cr steels [4–8]. The corrosion rate generally decreases as the Cr content increases [9]. Takabe and Ueda [10] found that the effect of C content on the corrosion resistance of 3%Cr steel was insignificant. Wu et al. [11] indicated that adding V and Nb to low-Cr alloy steel can form carbides that are more stable than Cr, resulting in a higher availability of Cr in the matrix.

Many previous studies have indicated that the higher performance of low-Cr alloy steel than that of C steel in a CO₂ environment is attributable to the enrichment of Cr in the corrosion scale, thus causing the scale to be more protective [1,3–8,10–13]. Ueda and Takabe [12] reported that the Cr content in the corrosion scale on 5%Cr steel after a 24-h immersion test was approximately 50 mass%, which was almost 10 times the content in the steel substrate. Chen et al. [14] found that the composition of a Cr-rich scale is mainly Cr(OH)₃ and FeCO₃. Zhang et al. [15] revealed that a thick, compact corrosion layer with a grading distribution of FeCO₃, Cr₂O_x, and

FeO formed on a 3%Cr steel surface. Hassani et al. [16] demonstrated that structures of corrosion products that formed on a 5%Cr steel surface were most likely amorphous or noncrystalline. Bai et al. [17] reported that the porosity of a corrosion scale on 4%Cr steel is lower than that of a corrosion scale on N80 steel, and the protective ability of a corrosion scale on 4%Cr steel is higher than that of a corrosion scale on N80 steel. Ko et al. [18] found that adding Cr (1%Cr steel) affected the corrosion process by considerably reducing the intensity of the anodic current density peak.

However, questions remain unanswered: (1) What substance resides on a steel surface before the formation of a thick and protective scale on low-Cr steel, and is the substance protective? (2) How does the Cr content affect corrosion performance? Few studies have addressed these questions. Therefore, a microscope with a camera was used in the present study for the in situ recording of 1%Cr–6.5%Cr steels surfaces during polarization. A considerable difference was found between 3%Cr–6.5%Cr steels and 1%Cr and 2%Cr steels. The results may reveal the role of Cr and the optimal Cr content in commercial low-Cr alloy steel.

2. Material and methods

2.1. Material and solution

The major elemental compositions of six kinds of low Cr steels with different Cr content are listed in Table 1, and the carbon steel X65 is used for comparison. The microstructure of X65 is Ferrite and Pearlite, and those of 1%Cr–6.5%Cr are Ferrite and Bai-

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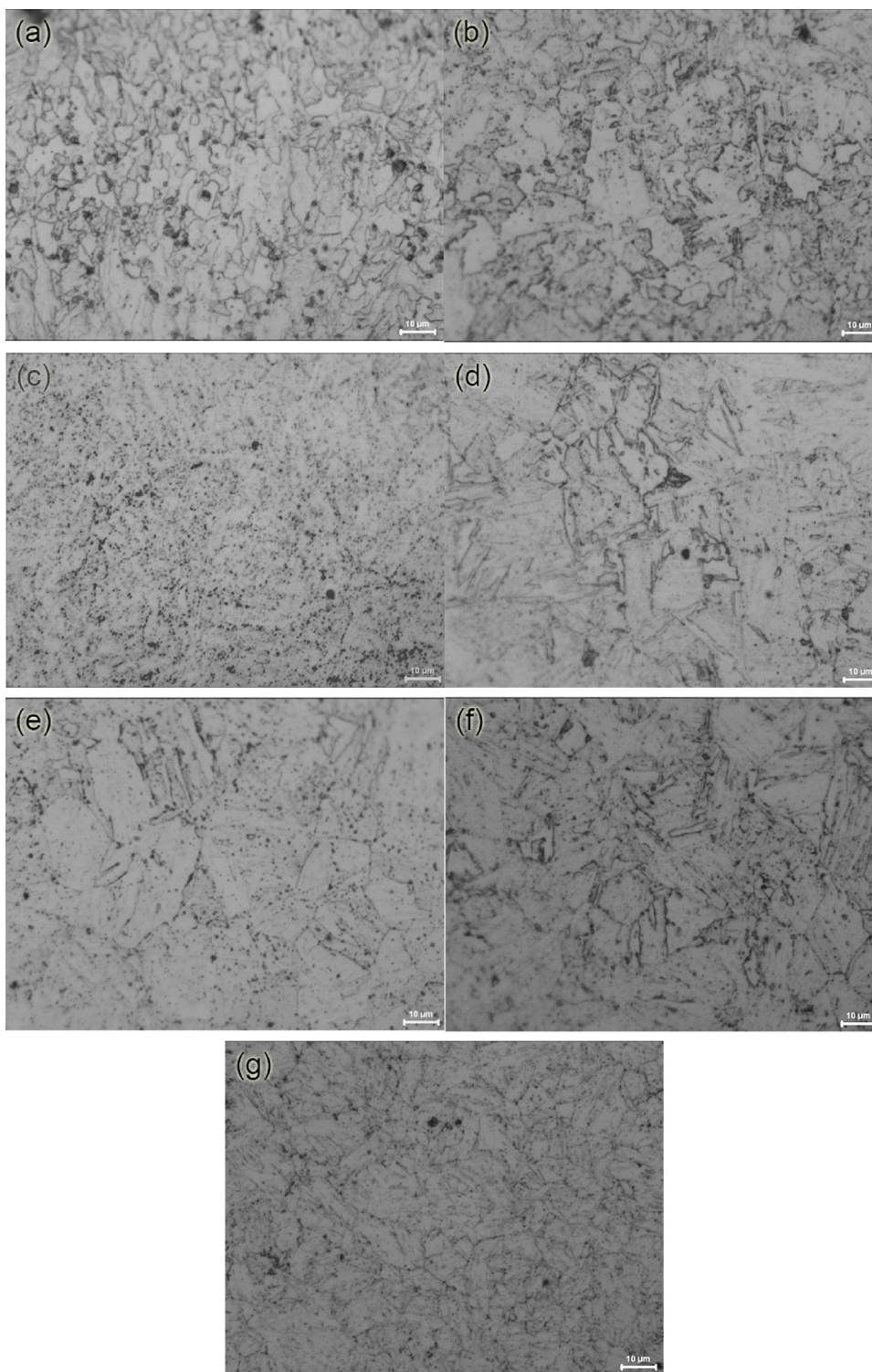


Fig. 1. Microstructure of X65 and 1%Cr–6.5%Cr steels (a) X65 (b) 1%Cr (c) 2%Cr (d) 3%Cr (e) 4%Cr (f) 5%Cr (g) 6.5%Cr.

nite (Fig. 1). The arc shaped specimens of 1/12 circle for weight loss tests were machined with dimensions of 87 mm in diameter and 12 mm in width. The electrodes for electrochemical measurements were embedded in epoxy resin with exposed working area of $10 \times 10 \text{ mm}^2$. Prior to each experiment, all the specimens were subsequently polished with 360, 800 and 1200 grit silicon carbide paper, rinsed with deionized water and degreased in acetone.

The test solution, simulating the formation water drawn out from oil and gas fields, was made from analytical grade

reagents and deionized water. Its ion composition is shown in Table 2

2.2. Weight loss tests

CO_2 corrosion tests were carried out in a 5 L autoclave under high temperature and high pressure condition. Seven individual tests were conducted for X65 and 1%Cr–6.5%Cr steels. Prior to weight loss tests, the original weight of specimen was measured with an

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