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The fracture toughness of CO_2 corrosion scale in pipeline steel

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Abstract

The fracture toughness of CO_2 corrosion scale in X65 pipeline steel has been measured using Vicker's indentation on a polished cross-section of the scale and the variation of the fracture toughness with scale forming temperature has been investigated. The results show that CO_2 corrosion scale formed at 65 °C to 90 °C is (Fe,Ca)CO_3 and that at 115 °C is (Fe,Ca,Mg)CO_3, respectively. The scale thickness decreases and the amount of Ca in the scale increases with increasing scale forming temperature. The fracture toughnesses of the outer and inner layers of the scale formed at 65 °C are 0.68 MPam$^{1/2}$ and 1.46 MPam$^{1/2}$, respectively. The fracture toughness of the CO_2 corrosion scale decreases with increasing scale forming temperature.

Keywords: CO_2 corrosion scale; Fracture toughness; Pipeline steel

1. Introduction

Carbon dioxide corrosion of carbon and low-alloy steels is a common problem in oil and gas industry [1]. The CO_2 corrosion scale has been determined as $FeCO_3$, which has been reported to be nonproductive below 60 °C, and protectiveness has been said to increase with temperature above 60 °C [2]. However, Ikeda et al. reported that above 100 °C, Fe_3O_4 and then Fe_2O_3 was formed, and $FeCO_3$ codeposition with Fe_3O_4 was considered hazardous [3]. Hassan et al. considered that for X52 pipeline steel corrosion product formed below 60 °C was $FeCO_3$, and that above 60 °C was $Fe(OH)_2CO_3$, which decreased the corrosion rate [4].

Cracking or locally breaking of the corrosion scale will cause pit or/and increase corrosion rate [5,6]. It is clear that the lower the fracture toughness of the scale, the easier to crack or break the scale during CO_2 corrosion. However, there is lack of the data of the fracture toughness of CO_2 corrosion scale. The fracture toughness, K_{IC}, of CO_2 corrosion scale in N80 tube steel was measured through Vicker's indentation on a polished surface with CO_2 corrosion scale [7]. The measured K_{IC}=7.2 MPam$^{1/2}$ is too high and is not valid fracture toughness of the scale. Because all equations of K_{IC} calculated through Vicker's indentation or nanoindentation are only suitable to bulk material [8,9]. For film, coating or scale on the surface of a matrix, the radial cracks can generate during indentation [10,11]. Up to now, however, there is no suitable equation to calculate K_{IC} of the composite material with different Young's modulus. When the film or scale is very thin because of polishing, the plastic deformation of the matrix metal will resist growth of the radial crack on the scale, resulting in higher apparent fracture toughness. Therefore, the only way to get real K_{IC} of film or scale is to use a polished cross-section sample with a film or scale over several micrometers.

The CO_2 corrosion scale formed at high temperature for a long time has a thickness over 10 μm [12]. By means of Vicker's indentation on a polished cross-section, it is possible to obtain a valid fracture toughness of the CO_2 corrosion scale. Thus, the objective of this paper is to measure the fracture toughness of CO_2 corrosion scale and to study the effect of microstructure on

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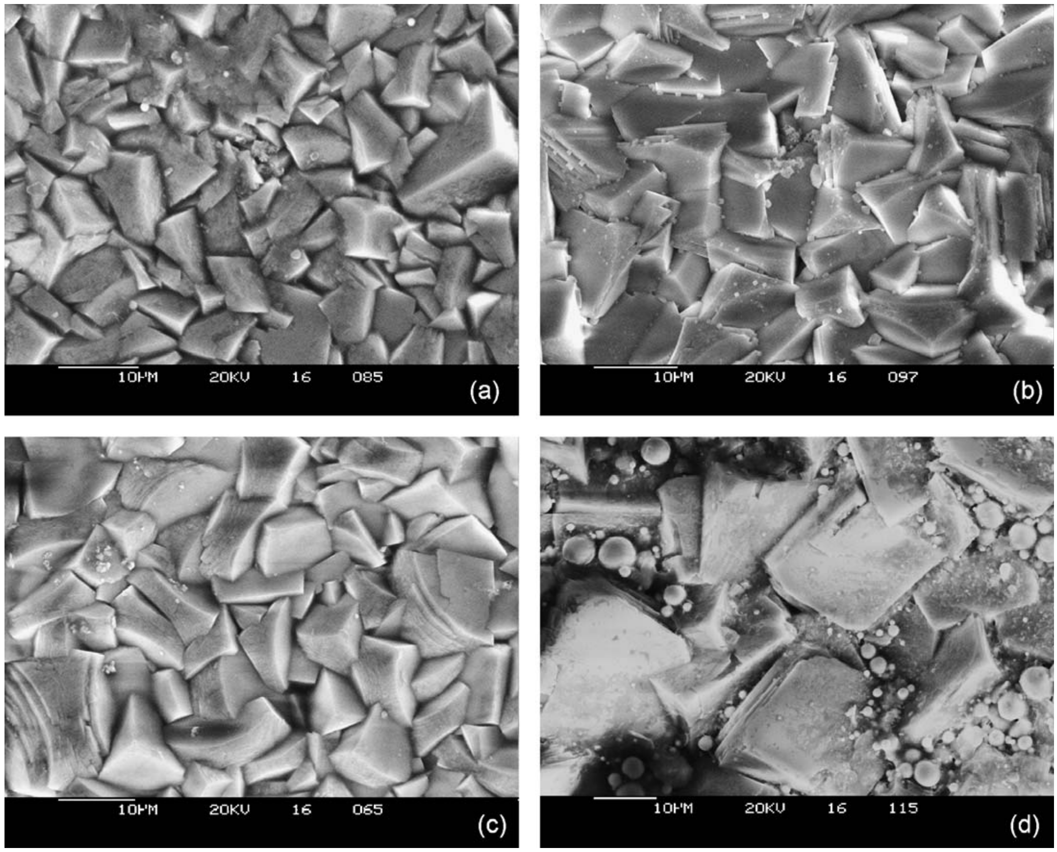

Fig. 1. Surface morphology of CO_2 corrosion scales formed at of 65 °C (a), 75 °C (b), 90 °C (c) and 115 °C (d).

the fracture toughness using the scales formed at various temperatures.

2. Experimental procedure

The chemical composition of X65 pipeline steel used in this study was 0.04 C, 0.2 Si, 1.5 Mn and 0.02 Mo. The polished and cleaned samples were put in the solution in an autoclave with CO_2 pressure of 1MPa. The solution had a composition in mg/L of 2568 $Na^{++}K^{+}$, 64 Ca^{2+}, 78 Mg^{2+}, 3580 Cl^{-}, 48 $SO_4^{2-}$and 863 HCO_3^{-}. CO_2 gas was allowed to bubble in the solution to remove oxygen. The solution was heated to 65 °C, 75 °C, 90 °C and 115 °C, respectively, and kept for 240 h.

After X-ray diffraction analysis and surface observation under SEM, the samples were sealed by epoxy, and then cut along the cross-section.

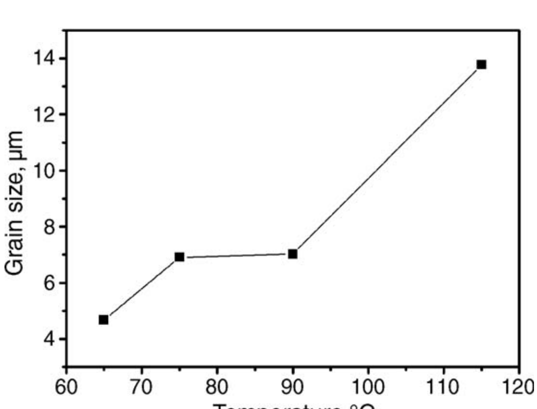

Fig. 2. Grain sizes of scales vs. scale forming temperature.

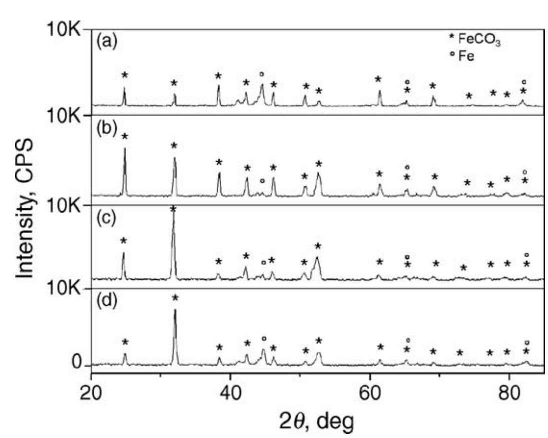

Fig. 3. XRD pattern of CO_2 corrosion scale formed at temperature of 65 °C (a), 75 °C (b), 90 °C (c) and 115 °C (d), respectively.