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Interaction of mechanical and electrochemical factors in erosion–corrosion of carbon steel

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Abstract

The interaction of mechanical and electrochemical factors in the erosion–corrosion process of carbon steel A1045 was investigated in Na_2SO_4 solution/silica sand slurry with a rotating cylinder electrode system. In line with the mechanism associated with material wastage, the synergism due to the interaction of erosion and corrosion was divided into corrosion-enhanced erosion and erosion-enhanced corrosion. The electrochemical experimental results indicated that the carbon steel showed active dissolution behavior, and the corrosion process was not controlled by the mass transfer when the rotating velocity is high enough. Scratching electrode tests and tensile tests were conducted to simulate the effect of sand impingement on corrosion process. Results showed that the impingement of the solid did not affect the corrosion behavior significantly in the present system. For the effect of corrosion on erosion, a half-logarithm relationship was found between weight loss due to corrosion-enhanced erosion and the applied anodic current density. According to a chemo-mechanical model, this effect can be attributed to the hardness degradation in metal surface with corrosion current.

Keywords: Erosion; Corrosion; Carbon steel; Synergistic effect; Chemo-mechanical model

1. Introduction

Erosion–corrosion occurs when a metal is exposed to flowing corrosive environment. The resulted mass loss is often much higher than ordinary summation of the mass loss due to pure erosion and that due to pure corrosion. The additional part is defined by the term of synergistic effect, which has a substantial contribution to the total material loss of the components suffering erosion–corrosion, especially in offshore, energy conversion, transporting and food processing systems.

The wastage of material in erosion–corrosion process, according to the mechanism of material loss, is considered to be the contributions due to electrochemical corrosion and mechanical erosion:

$$W_t = W_c + W_e \quad (1)$$

where

$$W_c = W_c^0 + W_c^e \quad (2)$$

and

$$W_e = W_e^0 + W_e^c \quad (3)$$

Here, W_t is the total mass loss of the material, W_c the corrosion component with the presence of erosion, W_e the erosion component with the presence of corrosion, W_c^0 the corrosion component free of erosion, W_e^0 the erosion component free of corrosion, W_c^e the corrosion component promoted by erosion and W_e^c is the erosion component enhanced by corrosion.

The total material loss caused by erosion-enhanced corrosion and corrosion-enhanced erosion is often regarded as the wastage produced by the synergistic effect, W_s

$$W_s = W_c^e + W_e^c \quad (4)$$

In most cases, W_s is greater than zero because the mechanical erosion and electrochemical corrosion interact and accelerate each other concurrently. Such a synergistic effect leads to a dramatic increase in damage rate. Li et al. [1] found that the synergistic effect was 40–50% of the total weight loss of aluminum in acidic slurry and 0.5 M NaCl slurry, although pure corrosion rate was only 0.03 and 0.67 mg/(cm^2 h), respec-

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tively. Matsumura and Oka [2] showed that the total weight loss of pure iron in NaOH slurry was 20% higher than that without corrosion, although the pure corrosion rate was too small to be measured. Yue et al. [3] found that when chrome white iron was eroded in low pH slurry, the contribution of the synergism could be as high as 86.3%. Neville et al. [4–8] conducted slurry-erosion tests with various metallic materials such as Co-based alloys, Ti-based alloys and stainless steels, etc., and results showed clearly the existence of a significant synergistic effect between erosion and corrosion.

Although the problem caused by the interaction of erosion and corrosion is very serious, the mechanism of synergy is still not thoroughly understood because of its complexity. Reyes and Neville [9], and Bester and Ball [10] proposed that the preferential dissolution of a matrix would lead to easy removal of the hard particles in microstructure, which sequentially results in acceleration of erosion. However, this assumption is only acceptable for the accelerated erosion by corrosion for materials strengthened with hard precipitates. It cannot be used to explain the effect in materials comprising mainly a single phased structure. Postlethwaite [11] pointed out that corrosion increases erosion rate by roughening the metal surface, because erosion rate is very sensitive to the impingement angle of solid particles. Recently, Li et al. [1] proposed a new mechanism that the localized attack at disruptions in the surface oxide (caused by the particle impacts) enhances the rate of the crack growth, causes the flakes to become detached and then leads to a higher erosion rate. Matsumura et al. [12] agreed that the increase in the surface roughness would play a role in synergism but they suggested that the impingement of particles would destruct the passive film and promote the dissolution of the work-hardened layer, which, in turn, would degrade the erosion resistance of material. Although the point presented by Matsumura et al. is qualitative, it is quite similar to the concept of chemo-mechanical effect proposed by Gutman [13], who pointed out that an extra dislocation flux would appear in the surface layer while anodic dissolution presents at the surface and result in a degradation of resistance in the surface layer to the plastic deformation.

The primary aim of the present investigation is to study the interaction and synergism between erosion and corrosion in an active dissolution system with an attempt to find the quantitative relationship between some parameters and the synergistic effect. The synergism of erosion and corrosion is discussed in term of erosion-enhanced corrosion and corrosion-enhanced erosion.

2. Experimental procedures

2.1. Test material and apparatus

The material used in this work was AISI 1045 carbon steel (A1045), and the nominal composition was: C, 0.43–0.50 wt.%; Mn, 0.60–0.90 wt.%; S, 0.05 wt.% (max); P, 0.04 wt.% (max); Fe balance. To obtain different hardness, some specimens were annealed at 500, 850 and 1050 °C in flowing argon for 1 h. The shape of the specimens was cylindrical with 8 mm in thickness and 25 mm in diameter. Before the commencement of tests, the work surfaces of samples were ground with silicon carbide abrasive paper up to 600-grit. The solution was 0.1 M Na_2SO_4 solution made by deionized water and analytical reagent grade sodium sulfate. Sand used was ungrounded silica sand with size of 212–300 μm, commercially available from U.S. Silica Company, Ottawa.

The experimental apparatus, a rotating cylinder electrode (RCE) system, is shown in Fig. 1(a). It was driven by an AFM-SRX rotator (Pine instrument Company, PA, USA) and the rotating velocity was adjustable in the range of 0–10,000 rpm. The cylindrical specimen holder was made of Teflon mounted on a stainless steel shaft while the specimens were mounted in the shaft with washers of PTFE and rubber to prevent crevice corrosion. A platinum wire, as the counter electrode, was placed in the bottom of the cell. A saturated calomel electrode (SCE) was employed as the reference electrode, connected by a salt bridge placed in the side cylinder. To prevent possible mingling action of the electrolytes, a rinsed porous ceramic was fixed between the major and side cylinders. The electrochemical measurements were carried out with a Gamry Corrosion Measurement System. All experiments were carried out with the velocity of 9000 rpm and 35 wt.% sand concentration except in few cases where running condition was specifically mentioned.

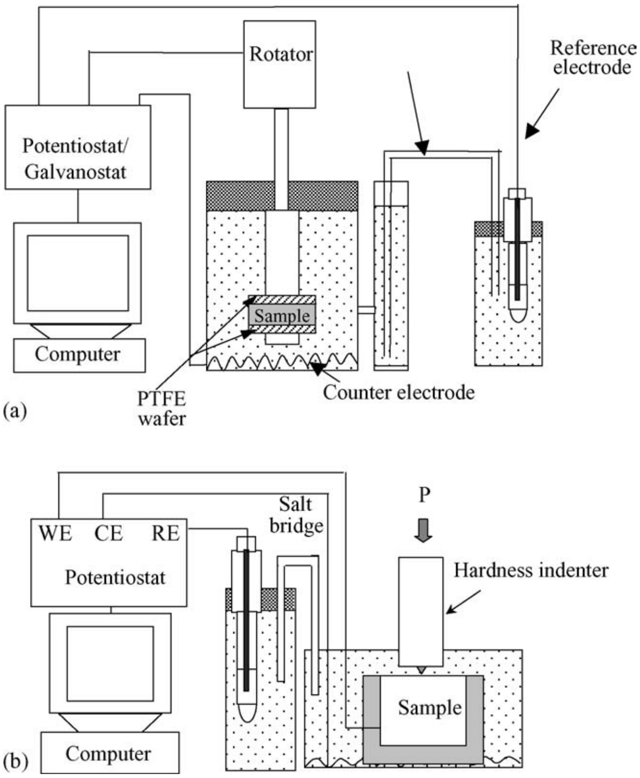

Fig. 1. Experimental apparatus for: (a) erosion–corrosion tests and (b) microhardness tests.