

Application of an electrochemical scratch technique to evaluate contributions of mechanical and electrochemical attacks to corrosive wear of materials

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Abstract

Corrosive wear is one of the most destructive processes encountered in industry. However, how the mechanical and electrochemical actions contribute to the material removal during corrosive wear is still not well understood. In this work, an electrochemical scratch method was applied to study the synergic attack of wear and corrosion to high-Cr cast iron, cast iron and mild steel in a 3.5% NaCl solution and tap water, respectively. Contributions of corrosion, wear and corrosion-wear synergism to the total material loss were evaluated using the technique in combination with other experiments, including polarization test, scratch profile measurement, scratch test under cathodic protection. The emphasis of the research was to evaluate how corrosion and wear mutually affected each other, which helped to understand the synergism of corrosion and wear for the materials. The contributions of mechanical and corrosion actions to corrosive wear of the materials were correlated to their mechanical and electrochemical properties. It was determined that the electrochemical scratch method was effective for investigating the synergism of wear and corrosion.

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1. Introduction

Many industrial facilities suffer from wear in corrosive environments. Corrosive wear may result in a high rate of material removal due to synergistic attack of corrosion and wear. The synergism of corrosion and wear has attracted wide attention [1]. Efforts have been made to develop experimental techniques to investigate corrosive wear. For example, an electrochemical erosion–corrosion apparatus was applied to study the interaction between wear and corrosion [2]. The corrosion-wear synergism may be expressed as the summation of additional wear caused by corrosion and additional corrosion caused by wear [3,4]. Attempts were made to evaluate the additional wear and corrosion. For instance, the effect of wear on corrosion of 18-8 austenitic stainless steels was

evaluated using a pin-on-disc apparatus [5]. The synergic effect of abrasive and corrosion on wear of low alloy steel was investigated using a pin-on-abrasive belt machine [6]. Kim et al. [7] investigated the synergism of wear and corrosion by examining the effect of applied load on the open circuit potential. Batchelor and Stachowiak [8] used a reciprocating sliding test rig to measure degradation rates of mild steel, zinc and magnesium during corrosive wear and investigate the corrosion-wear synergism based on the ratio of the static corrosion rate to the dry abrasion rate.

In recent years, the electrochemical scratch technique has been used to study not only the repassivation mechanism for passive metals and alloys [9,10] but also corrosive wear of the materials in corrosive environments [11,12]. Using this method, one may determine individual contributions of corrosion and wear to the total material loss [3].

However, although many methodologies have been proposed to investigate the wear-corrosion synergism in aqueous

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tribo-systems, it is still not easy to tell whether the mechanical behavior or the electrochemical behavior of a material dominates the synergistic attack of corrosion and wear under a specific condition. The objective of the present work was to determine individual contributions of wear and corrosion to corrosive wear of mild steel, cast iron and high-Cr cast iron respectively in a 3.5% NaCl solution and tap water using an electrochemical scratch method. The obtained information would be beneficial to fundamental understanding of the corrosion-wear synergism.

2. Experimental details

Commercial mild steel (wt.%: C 0.07%, Mn 0.67%, P 0.02%, S 0.02%, Fe balance), cast iron (wt.%: C 3.64%, Mn 0.18%, Si 2.44%, Fe balance) and high-Cr cast iron (wt.%: Cr 27.00%, Si 0.38%, Mn 1.39%, Fe balance) were chosen for the present study. Samples for electrochemical scratch and polarization tests had a size of 10 mm × 10 mm × 5 mm. Before the tests, all samples were mounted with epoxy. Sample surfaces were polished using silicon carbide papers from 240 to 600 grits, and finally polished with a 5 μm diamond paste. The test was performed in a 3.5% NaCl solution and tap water, respectively. Mechanical properties of the materials were evaluated by micro-indentation tests.

A Gamry electrochemical system was employed for the electrochemical tests. A saturated calomel electrode (SCE) was used as the reference electrode, and a platinum plate was used as the counter electrode. Polarization curves of the specimens were measured at a scan rate of 20 mV/min. All electrochemical tests were performed at room temperature.

The electrochemical scratch system is schematically shown in Fig. 1(a), which consists of two parts, an electrochemical sub-system that was used to control the applied potential or current and a mechanical sub-system used to scratch a target surface. Fig. 1(b) gives a diagram of the electrochemical cell. During the scratch test, variations in current with time were recorded, from which the additional corrosion due to wear could be evaluated. The mechanical sub-system consisted of a diamond tip (see Fig. 1(c)), a force sensor, and a computerized X–Z moving controlling system. During the electrochemical scratch test, a constant load of 20 g was applied and the tip moving velocity was 5 mm/s. The duration of the scratch was 0.8 s. Samples were polarized for 5 min under a testing potential before the electrochemical scratch. The applied potentials included the free corrosion potential and a cathodic one, respectively. A potential of -0.5 V relative to the free corrosion potential was applied as a cathodic protection potential. The wear loss under the cathodic potential was regarded as, approximately, the wear without the influence of corrosion.

Morphologies of scratch grooves were examined using an atomic force microscope (AFM), which allowed to determine the cross-sectional profile of a scratched groove. The dimensions of the scratched groove profile determined the material

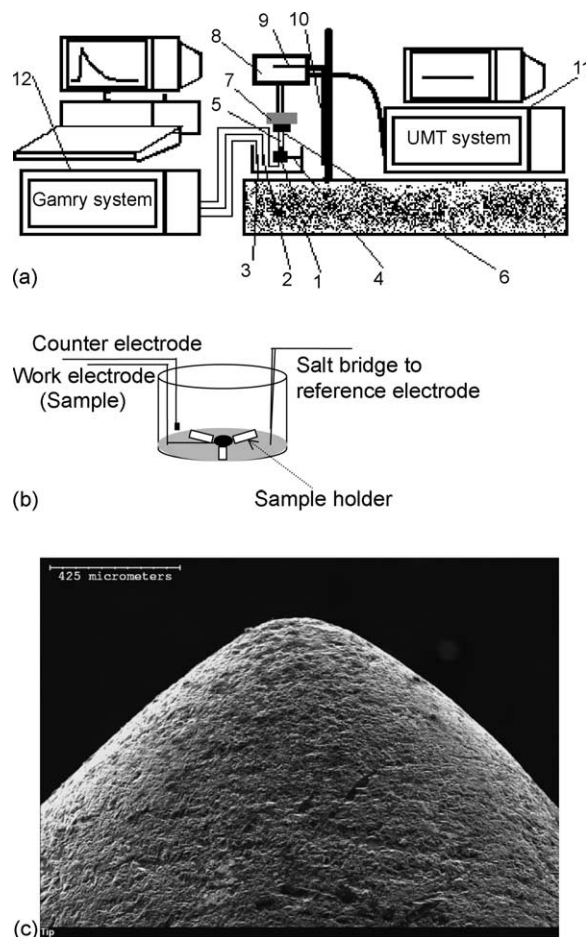


Fig. 1. (a) Schematic illustration of the electrochemical scratch system: (1) the sample for scratch test; (2) the counter electrode; (3) the reference electrode; (4) an electrochemical cell and the sample holder; (5) a diamond tip for the scratching test; (6) the tip holder; (7) a force sensor; (8) a control unit for lateral and vertical movement of the scratch tip; (9) a track for the scratching tip to move along the lateral direction; (10) a track for the scratching tip to move along the vertical direction; (11) an electrochemical data acquisition and analysis system (Gamry system); (12) a force control and data acquisition system. (b) A closer view of the electrochemical cell. (c) The shape of the diamond tip.

loss caused by scratch that was affected by pure wear, corrosion and the synergism of corrosion and wear.

3. Results

3.1. Electrochemical properties and the mechanical behavior

In order to better understand the effect of corrosion on the synergic removal of a material caused by electrochemical scratch, the electrochemical behavior of the material (polarization curves, polarization resistance and Tafel curves) needs to be investigated. Polarization curves of mild steel, cast iron and high-Cr cast iron in tap water and the 3.5% NaCl solution were obtained and are shown in Fig. 2(a) and (b), re-