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The role of heat treatment on the erosion–corrosion behavior of AISI 52100 steel

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Abstract

The role of heat treatment on the erosion and corrosion behavior of 52100 steel was investigated in terms of: (i) electrochemical parameter measurements, (ii) identification of microstrain and strain energy induced by erosion, and (iii) the characterization of synergistic effect between erosion and corrosion. Heat-treatment both thermodynamically and kinetically affects the electrochemical reaction of eroded 52100 steel.

Based on both the polarization resistance and corrosion rate measurements, it was found that a tempering treatment gives rise to the slowest corrosion kinetics. For both the annealed and tempered specimens, where the microstrain is created solely from mechanical deformation during erosion, there is a reasonable agreement between the calculated corrosion rate based on a mechano-electrochemical effect and the experimentally measured corrosion rate. However, for the quenched specimens in which a high level of microstrain is generated on quenching, there is a significant difference between the calculated (from mechano-electrochemical effect) and experimentally measured corrosion rates.

Keywords: Erosion; Corrosion; Heat treatment; Electrochemical; 52100 steel; Synergistic effect

1. Introduction

In the chemical, mining, power and building material industries, components of equipment which transport various slurries, often fail in a relatively short time. This problem has been, and remains of, world-wide concern and much research has been done on this topic [1–5]. Corrosive wear is a highly visible failure mode in those industries, but more work on the synergistic effects between corrosion and wear is, however, still needed [6–9].

Material losses of the grinding media are due to the joint actions of impact and abrasion, and corrosion [10–13]. The overall process of corrosive wear can be resolved into two elementary processes, namely a corrosion process and wear by slurry abrasion [14,15].

High stress collisions between the grinding media and the ore charge in the mill lead to direct mechanical loss of metal from the ball surfaces, resulting in abrasive wear. Impact wear, resulting from large fall heights, is determined by surface hardness, spalling tendency and resistance to breakage under the impact of the grinding media.

The hardness of the grinding media is a determining parameter in the material losses due to dry wear, abrasion, and it also shifts the potentiodynamic polarization curves, resulting in a different corrosion potential and corresponding corrosion rate [16]. Due to the synergistic effect between erosion and corrosion, the hardness and the corrosion resistance are two controlling parameters and should be investigated in order to reduce material losses.

In this study, the synergistic effect between erosion and corrosion of heat-treated 52100 steel was investigated using

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the electrochemical parameter, microstrain and strain energy measurements.

2. Experimental details

2.1. Materials and heat treatment

The material used in this investigation was an AISI 52100 bearing steel. This was chosen to represent the high carbon, low alloy steels being used in the commercial grinding industries. The chemical composition (wt.%) was 1.05 C, 1.70 Cr, 0.34 Mn, 0.06 Mo, 0.18 Ni, 0.26 Si, 0.12 Cu, 0.016 S, balance Fe.

All the specimens for erosion, corrosion and electrochemical testing were in the form of plates with dimensions: 50 mm length, 25 mm width and 2 mm thickness. The specimens were polished using SiC abrasive papers, #180 to #600 grit, before they were subjected to heat treatment, erosion–corrosion testing and electrochemical measurements.

The heat treatments included annealing, quenching and tempering. The annealing was carried out by holding for 1 h at 750 °C, and then furnace cooling to room temperature. The quenching treatment was performed by holding for one hour at 900 °C, then quenching the heated samples into water. Tempering was carried out on the quenched specimens for 10 h at 650 °C [17].

After the heat treated specimens were removed from the furnace or quenching media, the outer layer of loose oxide was mechanically removed using a plastic plate. The specimens were then immersed in a hydrochloric acid solution containing 50% HCl (36%) and 50% water [18], and stirred using a glass rod to electrochemically dissolve the inner layer of oxide. The specimens were thoroughly rinsed using tap water in order to remove any acid residue on the surface, and then completely dried to avoid further corrosion. The specimens with a clean and active surface were then ready for the erosion, corrosion and electrochemical measurements/testing.

2.2. Erosion testing

Dry erosion was conducted in a custom-made erosion tester with SiC particles as the erodent. The SiC particles were accelerated with pressurized air in a long horizontal tube. The erosion angle was set at 45° and the total erosion weights were 10, 50 and 100 g of SiC particles [16].

2.3. Electrochemical measurements

The electrochemical measurements were conducted in a tri-electrode cell with a saturated calomel electrode (SCE) as the reference electrode (RE) and a graphite plate as the counter electrode (CE). Electrochemical measurements were carried out in 2 g/l NaCl and 2 g/l Na_2SO_4 solutions to simulate the chemical composition of practical ore grinding process solutions (adjusted to neutral pH) on both eroded and uneroded specimens using a *Solartron* 1285 potentiostat.

The measured electrochemical parameters included the open-circuit potential, polarization resistance (R_p), corrosion potential, Tafel slopes (β_a and β_c), corrosion rate, linear polarization curves and Tafel potentiodynamic polarization curves. Based on the electrochemical parameters and the strain energy, a synergistic effect between erosion and corrosion was evaluated.

2.4. Measurements of the microstrain induced by erosion of heat-treated 52100 steel

XRD analysis was used to characterize the microstrain induced by the impact of SiC particles. The corresponding stored strain energy can be calculated from this microstrain and the synergistic effect correlating strain energy and electrochemical potential can be characterized. A Phillips X-ray diffractometer with a proportional counter detection head was used. Graphite monochromated Cukα radiation, at a voltage of 40 kV and a current of 20 mA, was utilized as the diffracting medium.

The AISI 52100 steel was first fully annealed in order to determine the instrumental broadening (all the broadening of the diffraction peaks for an fully annealed specimen is assumed to be only from instrumental effects). The scanning angles (2θ) were from 30 to 150° at a scanning step of 0.5°. A XRD pattern of intensity versus 2θ was obtained. There were six peaks recorded for each heat-treated specimen and the peak positions were determined. Then, the heat-treated and eroded specimens were scanned again at a scanning rate of 0.02° in a small angular range around the six peaks to determine the broadening of the XRD peaks.

From the broadening of the XRD peaks, the microstrain due to erosion can be calculated [18,19]. The broadening is determined by measuring the width B, in radians, at an intensity equal to half the maximum intensity. If the observed X-ray peak of eroded specimen has a width B_o, and the width due to instrumental effects is B_i, then the remaining width B_r is due to the combined effects of crystallite size and microstrain [18]:

$$B_r = \sqrt{B_o^2 - B_i^2} \tag{1}$$

According to Suryanarayana and Norton [20]:

$$B_r \cos\theta = \eta \sin\theta + \frac{k\lambda}{L} \tag{2}$$

where, k is a constant, λ is the wavelength of incident X-ray, L is the average crystallite size and η is the microstrain. The microstrain can be obtained from the slope of the plot of $B_r \cos\theta$ versus $\sin\theta$.