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Interfacial morphology and corrosion-wear behavior of cast Fe-3.5 wt.% B steel in liquid zinc

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ABSTRACT

The corrosion-wear behavior of Fe-3.5 wt.%B steel in liquid zinc was investigated via the block-against-ring technique. Owing to the protective ability of the Fe_2B phase, this steel exhibited better corrosion-wear resistance than a 316L stainless steel. SEM, XRD, and EDS of the corrosion-wear interface indicated that the corrosion-wear process of Fe-3.5 wt.%B steel consists of the following steps: corrosion of the matrix, fragmentation and removal of $FeZn_{13}$, and failure of the Fe_2B. The intensified mechanical effect of wear resulted in significant deterioration (via fracture and removal of $FeZn_{13}$, and spallation Fe_2B) of corrosion-wear interface, which exacerbated corrosion, and facilitated the corrosion-wear process.

1. Introduction

In continuous hot dip galvanizing, pot hardware (including rolls and supporting bearings), which is used to guide incoming steel strips passing through a zinc pot, is submerged in molten zinc [1,2]. Owing to the arduous working environment, i.e., elevated temperature (450–470 °C) and a corrosive medium (molten zinc), the selection of proper hardware materials prolonged operation is rather challenging. Corrosion and erosion-corrosion behaviors of materials in a liquid zinc bath have been extensively investigated with the aim of developing improved hardware materials for galvanization and service-life prolongation of these parts [3–12]. However, corrosive wear of important components (such as sink roll and steel strip, bearings and sleeves) is detrimental to these parts [2,13–15]. Compared with corrosion or erosion-corrosion, corrosion-wear (i.e., the intensified wear-induced mechanical process of material removal, coupled with mechanical erosion and the chemical process of corrosion) results in more severe damage to these parts [16,17]. The accelerated damage to these parts yields significant reduction in the quality and productivity of plated steel.

Zhang et al. investigated the corrosion-wear behavior of cobalt-based superalloys in a zinc bath, and found that the worn surfaces of these alloys were fully covered by wide and deep grooves. This indicated that wear is the main factor resulting in material loss [13,18], consistent with the findings reported by Kim et al. [15,19]. Snider investigated the corrosion-wear behavior of cobalt and MSA 2012 XT in liquid zinc, and found that static corrosion may exacerbate the wear process by corroding the wear surface of this alloy. This, in turn, facilitates the corrosion-wear process, thereby resulting in significant material loss [16]. The corrosion-wear behavior of ferry alloy in liquid zinc has, however, rarely been studied, and the corrosion effect on the corrosion-wear process is neglected in most corrosion-wear cases.

Recently, two-phase Fe-B steel, composed of an Fe_2B erosion-resistant phase and the α-Fe matrix, has received significant attention [20–23]. The unique microstructure of this steel results in outstanding properties, such as high hardness, process performance, and good corrosion resistance to molten zinc. This is especially true for steel with a boron content of 3.5 wt.%, and a corrosion-resistant phase that accounts for 41.5 vol.% of the microstructure. At this fraction, the corrosion-resistant phase provides both adequate mechanical strength and corrosion resistance to liquid zinc (i.e., the corrosion resistance and mechanical properties are balanced based on the amount of Fe_2B). Previous studies have shown that the good erosion resistance of Fe-3.5 wt.% B steel in flowing zinc results from barrier effect of Fe_2B [24–27].

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Table 1
Chemical composition of the investigated Fe-B alloy and 316L stainless/wt.%.

Elements	B	C	Mn	P	Si	Cr	Ni	Fe
Fe-B	3.48	0.22	–	–	0.59	0.78	–	Bal.
316L	–	0.024	1.191	0.0371	0.59	17.09	10.41	Bal.

However, studies focused on the corrosion-wear behavior of Fe-3.5 wt.% B steel in liquid zinc have rarely been reported. Therefore, in the present work, the interfacial characteristics and corrosion-wear behavior of Fe-3.5 wt.% B steel in liquid zinc at 460 °C were investigated. The effect of wear on corrosion, and corrosion-wear behaviors was discussed, and the corrosion-wear mechanism of this steel (in liquid zinc) was determined.

2. Materials and methods

2.1. Materials

Fe-3.5 wt.% B steel under investigation was melted in a 10 kg-capacity medium-frequency induction furnace. In the early stage, clean pure iron, Fe-19.80 wt.% B ferro-steel and steel scrap were added to the furnace and then a little Al was added to slag-free molten steel to minimize oxidation loss and slag formation. The Fe-3.5 wt.% B steel subsequently superheated to 1550–1600 °C and then poured at 1420 °C into a Y type sand mold to solidify desired microstructures. Eventually, the as-cast ingots were cleaned and cut into desired corrosion-wear specimens by wire electric discharge machine. The chemical composition of Fe-3.5 wt.% B steel, analyzed by X-ray fluorescence spectroscopy (LAB CENTER XRF-1800), is listed in Table 1.

2.2. Corrosion-wear tests

The corrosive wear tests of Fe-3.5 wt.% B steel against itself were conducted on a ring-against-block wear-testing apparatus, as shown in Fig. 1. The wear specimen was made of block-shaped Fe-3.5 wt.% B steel with dimension of 70 × 20 × 10 mm. The HRC value of Fe-3.5 wt.% B steel, measured by an HRS-150 Rockwell-hardness tester at room temperature, is 45.23. The opposite wear specimen was made of ring-shaped Fe-3.5 wt.% B steel with a size of 100 mm outer diameter, and 20 mm thickness. Conventional 316L stainless steel was selected as the reference sample. The composition of 316L stainless steel is listed in Table 1.

Prior to corrosion-wear test, the specimens were ground by 2000 mesh carborundum paper and washed with alcohol and acetone. To ensure that iron in the liquid zinc was unsaturated, 30 kg pure zinc (99.99 wt.%) was melted (i.e., the volume of liquid zinc is about 4.6×10^{-3} m^3) in an alumina crucible in each corrosion–wear test. A K-type thermocouple was immersed into liquid zinc bath to monitor the temperature. The ring specimen made of Fe-3.5 wt.% B steel was then fixed on the terminal of the rotational shaft, and the block specimen, which is made of Fe-3.5 wt.% B steel, was fixed on the terminal of the load-applying pole, as is shown in Fig. 1. The load was applied the desired value. Corrosion-wear tests were then performed in liquid zinc bath. The test conditions are given in Table 2. It is to be noted that, during the corrosion-wear process, the wear and opposite wear specimens (i.e., the block and ring-shaped specimens) are always contacted closely and their contacting surfaces are also adjusted to be parallel in vertical direction. After corrosion-wear test, in order to protect the corrosion-wear layer, the block and ring specimens were together removed from liquid zinc and then separated from each other.

2.3. Measurement of corrosion-wear rate

These tested specimens were sectioned based on the schematic in Fig. 2 and then polished in prepared for arc length measures and interface analysis using microscope and SEM, respectively. The following equation was used to estimate corrosion-wear volume loss of the tested specimens.

$$V = h\left\{\frac{\pi}{180}\cdot\frac{r^2}{2}\cdot\arcsin\left(\frac{a}{R}\right) - \frac{1}{2}\cdot a\cdot(r-b)\right\} \tag{1}$$

where V is the volumes loss caused by corrosion-wear (mm^3); h is the height of the ring (20 mm); r is the radius of ring (mm), a is the width of arc caused by corrosion-wear (mm), and b is the depth of arc caused by corrosion-wear (mm), and the arcsine is in degrees. The corrosion-wear rate can be calculated by the following Eq. (2).

$$R = \frac{V}{L} \tag{2}$$

where R, L are the generalized corrosion-wear rate (mm^3 m^{-1}) and the total wear distance (m), respectively. It is to be noted that, every data results from the average value of three corrosion-wear measurements.

2.4. Characterization

The microstructure of as-cast specimens and the interface morphologies of corrosion-wear specimens were analyzed by a scanning electron microscopy (SEM) (Tescan VEGA II XMU, Brno, Czech

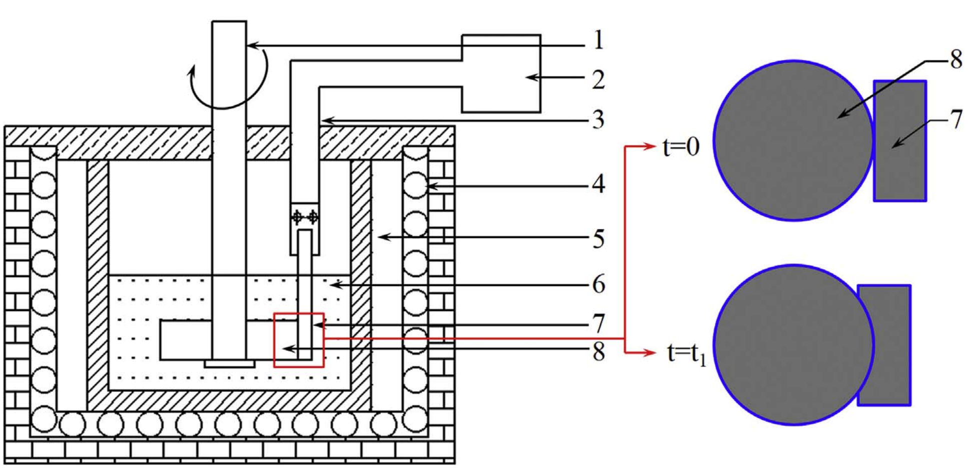

Fig. 1. Schematic map of the corrosion-wear testing device: 1-Rotating shaft; 2- Load applying system; 3-Load applying pole; 4-Furenace; 5-Crucible; 6-liquid zinc; 7-Tested block specimens; 8-Ring specimens.