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Effect of Fe₂B orientation on erosion–corrosion behavior of Fe–3.5 wt.% B steel in flowing zinc

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ABSTRACT

The effect of Fe₂B orientation in Fe–3.5 wt.% B steel on its erosion–corrosion behavior in 460 °C flowing zinc was investigated. The results indicate that the erosion–corrosion resistance of Fe–3.5 wt.% B steel relies strongly on Fe₂B orientation. The orientation of Fe₂B determines the erosion–corrosion interface, which governs the diffusion, interfacial reaction, failure mode of Fe₂B, and significantly influences the erosion–corrosion behavior. The strong pinning effect of corrosion products and columnar Fe₂B suppresses erosion–corrosion; this suppression results in good erosion–corrosion resistance to liquid zinc of the Fe–3.5 wt.% B steel with the [0 0 2] direction of Fe₂B perpendicular to the erosion–corrosion interface.

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1. Introduction

Hot-dip coating is used extensively in industrial applications as an effective corrosion protection method [1,2]. As such, many investigations on the corrosion behavior of metal in static liquid zinc have been conducted in the galvanizing industry [3–5]. In a continuous galvanizing line (CGL), the immersed bath equipment (e.g., sink, stabilizer rolls, and supporting bearing) is subjected to rigorous erosion–corrosion attack from the molten zinc; this attack results from the relative flow velocity of the surface of the immersed parts and molten zinc, which accelerates the deterioration of the parts [6–8]. Moreover, the accelerated deterioration leads to significant economic losses incurred from maintenance and replacement of the eroded parts.

In order to prolong the service life of galvanizing parts, particular emphasis has recently been placed on the development of new liquid-zinc-corrosion-resistant materials [4,9,10]. Many studies have shown that a boronizing treatment can improve the corrosion resistance of the material to molten zinc; this resistance stems from the formation of Fe₂B and FeB intermetallic phases in the surface of the material [11–13]. However, a boronizing layer

is always prone to spalling, and hence its use in galvanizing is limited. Cast Fe–B steel has received significant attention due to its unique structure, which is composed of two-phase microstructures of an Fe₂B corrosion-resistant phase and a ductile α -Fe matrix; this steel has high hardness, is easily processed and exhibits good corrosion resistance to molten zinc [14–16]. Our previous studies of Fe–B steel showed that 3.5 wt.% of boron resulted in an about 41.5 vol.% of corrosion-resistant phase. This amount of corrosion-resistant phase provides both adequate corrosion resistance to liquid zinc and mechanical strength (i.e., the corrosion resistance and mechanical properties are balanced based on the amount of Fe₂B) [16,17]. Therefore, Fe–B steel containing 3.5 wt.% B has significant potential for use in the manufacture of parts for galvanizing equipment.

Previous studies have indicated that the crystal orientation has a significant effect on the plastic deformation and strength of a metal, direction of intergranular crack propagation, oxidation dissolution, and corrosion behavior [18–24]. This effect stems from the close-packed planes of the crystal, whose high atomic coordination and binding energy, leads to good material properties. Furthermore, Coronado reported that the M₇C₃ carbides in white cast exhibit higher microhardness in the transverse direction than in the longitudinal direction. However, the longitudinal M₇C₃ carbides exhibit higher fracture toughness in the direction perpendicular to the larger edge of the carbide, than in directions either parallel

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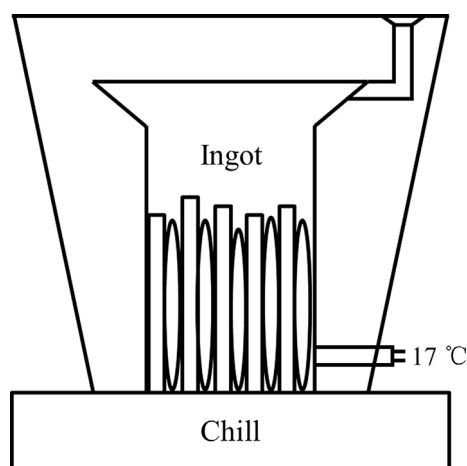


Fig. 1. Schematic device of directional solidified cast Fe–3.5 wt.% B steel (solidification rate of about 17 °C measured by a thermocouple).

to the larger edge, or in the transverse section [22]. In addition, Liu et al. [18] found that during the corrosion of magnesium in HCl, grains having a near (0001) orientation exhibit the best corrosion resistance. Based on the aforementioned investigations, it can be inferred that the orientation of Fe₂B boride in Fe–3.5 wt.% B steel may influence its erosion–corrosion resistance to flowing zinc.

Therefore, in the present work, erosion–corrosion tests were performed in a flowing zinc bath on cast Fe–3.5 wt.% B steel with non-oriented and oriented Fe₂B boride. Furthermore, the mechanism governing the effect of Fe₂B orientation on the erosion–corrosion behavior of the steel was discussed.

2. Material and methods

2.1. Sample preparation of Fe–3.5 wt.% B steel

The investigated Fe–3.5 wt.% B steel was melted in a 10 kg-capacity medium frequency induction furnace. Fig. 1 shows a schematic of the equipment used to directionally solidify the Fe–3.5 wt.% B steel (i.e., the Fe–3.5 wt.% B steel with oriented Fe₂B boride) with a longitudinal thermal gradient. In the initial stage, clean pure iron, Fe–19.80 wt.% B ferro-alloy, and steel scrap were placed in the furnace; 0.10 wt.% Al was then appended to the slag-free molten steel in order to minimize the oxidation loss and slag formation. The Fe–3.5 wt.% B steels with non-oriented and oriented Fe₂B boride were melted at 1550–1600 °C and then poured into a sand mold at 1420–1450 °C, in order to obtain the desired solidified microstructures. The directional region near the chill was cut at the location where the solidification temperature of the sample was about 17 °C, as measured by a thermocouple (Fig. 1); only the

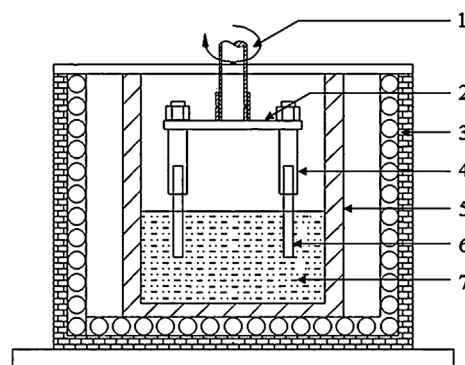


Fig. 3. Schematic map of the erosion–corrosion testing device: 1 – rotation shaft; 2 – disk for controlling erosion angle; 3 – furnace; 4 – specimen holder; 5 – crucible; 6 – test specimen; 7 – liquid zinc.

large columnar boride oriented from the chill toward the center of the casting was used in flowing liquid zinc erosion–corrosion test. Table 1 list the chemical composition of the steel, as determined by a spark emission spectrometer. The long axis of the Fe₂B boride in the directional samples eroded in the flowing liquid zinc, was either perpendicular or parallel to the erosion–corrosion interface. Therefore, there are three possible configurations of the Fe₂B boride orientation with respect to the erosion–corrosion interface of liquid zinc (as shown in Fig. 2a–c).

2.2. Erosion–corrosion test

Prior to the flowing zinc erosion–corrosion test, the samples were ground by 2000 mesh carborundum paper and washed with alcohol and acetone. The initial thickness between the two faces of the tested samples was obtained from the average value of twelve measurements performed at multiple locations, using a micrometer. A schematic of the erosion–corrosion tester is shown in Fig. 3. To ensure that the iron in the liquid zinc was unsaturated, 30 kg of pure zinc (99.99 wt.%) was melted (i.e., the volume of liquid zinc is about $4.6 \times 10^{-3} \text{ m}^3$) in the silicon nitride crucible for each erosion–corrosion test; a K-type thermocouple was immersed into the liquid zinc to monitor the temperature. Erosion–corrosion tests, with various modes of erosion–corrosion, were then performed in flowing liquid zinc using the rotating-disk technique at a liquid zinc temperature of 460 °C. A rotating disk speed of 60 rpm (i.e., 0.314 m s^{-1}) was used, based on the relative velocity of the surface of the immersed parts and molten zinc in a continuous hot-dipping line [25]. The erosion time varied from 1 to 7 h in 1 h interval. The eroded samples were then removed from the liquid zinc and implanted in the resin. Based on the procedure outlined in Refs. [4,17,26], the thickness of each erosion–corrosion sample was measured microscopically in 1-mm-intervals across the

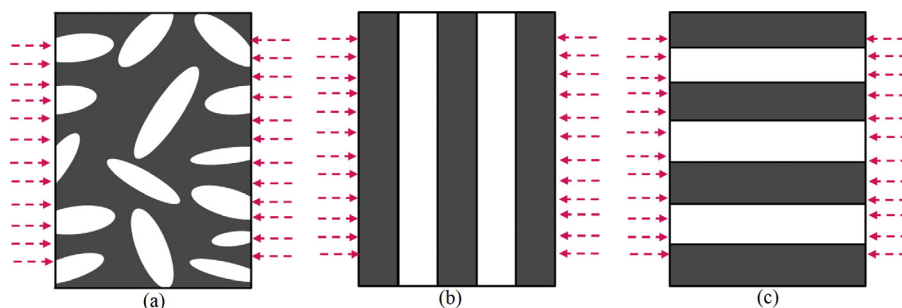


Fig. 2. The erosion–corrosion manners of as-cast Fe–3.5 wt.% B steel: (a) non-oriented sample; (b) parallel sample (i.e. preferred growth direction of Fe₂B parallel to erosion–corrosion interface); (c) vertical sample (i.e. preferred growth direction of Fe₂B perpendicular to erosion–corrosion interface).

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