**Effect of temperature on the performance of sherardizing coating**

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**Abstract.** To investigate the effect of the sherardizing temperature on the coating performance, several experiments were made at 380℃, 390℃, 400℃, 410℃ and 420 ℃ for 4h. The coating composition, morphology, thickness, mass, and microhardness were analyzed. The results show that the coating is continuous, dense and uniform. The coating is mainly formed by the diffusion of Zn and Fe atoms, and has a two-phase structure. The top layer is a thick FeZn10 phase, and the subjacent layer is a thin Fe11Zn40 phase. With the increase of temperature, the morphology and microhardness of coating change little, but the coating thickness and mass increase gradually.

1. Introduction

As an important part of modern materials, steel has been widely used in the fields of petroleum, metallurgy, electric power and so on [1]. However, steel is easy to be corroded by atmosphere, soil and other media, which leads to material failure and economic loss, and also leads to potential safety hazards. Therefore, how to improve the corrosion resistance of steel materials has been the focus of researchers.

Sherardizing process is an effective metal protection technology, which uses the thermal diffusion theory to form an alloy layer on the surface of steel part to prevent the material from being damaged by corrosion [2]. Liu et al. reported that the sherardizing steel has much better corrosion resistance than untreated in 3.5% NaCl solution [3]. He et al. studied that the sherardized steel has excellent sulphidation resistance, whose weight gains are about 1/10 of that of 18Cr–9Ni and 2/5 of carbon steel [4].

According to the literature, due to the slow diffusion of atoms, there are some problems in the sherardizing process, such as the thin coating thickness and low efficiency [5]. According to the Arrhenius equation, temperature is one of the main factors that affects the diffusion rate of atoms [6]. Therefore, it can improve the sherardizing efficiency and the coating performance to optimize the temperature parameter. In this paper, the influence of sherardizing temperature on the morphology, thickness, and hardness of the coating was studied in order to provide a reference for the application of sherardizing process.

2. Experimental

Sherardizing by means of pack cementation was carried out in this work. The pack powder consisted of 2wt.% NH4Cl and 2wt.% ZnCl, which acted as the chemical activator, 78wt.% Zn, 2wt.% La2O3, and balanced Al2O3 as the inert filler. The Q235 steel was selected as the sample material. The samples and the zinc powder were sealed in a quartz boat, and the samples should be fully embedded in the powder. Then the sealed quartz boat were placed in a vacuum furnace. Experiments were made at 350℃, 370℃, 390℃, 410℃ and 430℃. The holding time of the heating process was 4h.
The cross-sectional morphology and thickness of the coating was obtained by optical microscope (OM). The microstructure and composition of the coating were analyzed using scanning electron microscopy (SEM) and energy dispersive spectrum (EDS), respectively. The phases of the coating were examined by X-ray diffraction (XRD). The micro-hardness and mass of the coating were respectively measured using HV-1000 type micro-sclerometer and electronic balance.

3. Results and discussion

3.1. Structure and composition of the coating

Figure 1 shows the microstructure and element distribution of the coating obtained at 410℃ for 4h. Figure 2. is the XRD pattern of the coating shown in Figure 1.

As shown in Figure 1(a), there is a clear boundary between the coating and the substrate. The coating possesses a uniform thickness, and there are no cracks and holes in the layer. According to Figure 1(b), it is obvious that both Zn and Fe element are detected in the substrate and coating, indicating the occurrence of sherardizing process. From the coating’s surface to the substrate, the content of Zn decreases slowly, while the content of Fe increases slowly. Therefore, the coating is formed by the diffusion of the Zn and Fe atoms. The XRD analysis reveals that the coating contains the FeZn10 and Fe11Zn40 phase, which belong to four intermetallic phases present in the Zn–Fe binary phase diagram [7].

3.2. The effect of the temperature on the morphology

Figure 3 shows the cross-sectional morphology of the coating formed at different temperature for 4h. With the temperature rising from 380℃ to 420℃, the morphology of the coating remains unchanged, which is similar to that in Figure 1(a). The coating is uniform and dense, which is compose of A and B region. The coating contains FeZn10 phase and Fe11Zn40 phase according to the Figure 2. This phase composition is same to the research conducted by Kania [8] et al. And they have proved that Fe11Zn40 phase is next to the substrate (B region), the out layer (A region) is FeZn10 phase. What's more, the coating thickness is thin when the temperature is 380℃, but increases significantly when the temperature
varies from 400℃ to 420℃.

Figure 3. Micro-morphology of the coating obtained at different temperatures: (a) 380℃, (b) 400℃, (c) 410℃, (d) 420℃

3.3. The effect of the temperature on the microhardness

The microhardness of zinc coating formed at different temperature is shown in Figure 4. The hardness values are 225.48HV, 339.49HV, 342.77HV, 346.85HV and 269.99HV, respectively. With the increase of temperature, the hardness value has little change. The main phases of Zn-Fe alloy are ζ phase (FeZn13), δ phase (FeZn10) and Γ phase (Fe11Zn40), according to Zn–Fe binary phase diagram. Their microhardness numbers are 118~208HV, 273~358HV and 505HV respectively [7]. The coating microhardness is close to that of δ phase. As shown in Figure 3, the thickness of A region is thicker than that of B region. So the hardness values obtained in the experiment is mainly that of A region. In totally, the out coating (A region) is mainly composed by δ phase, consistent with the analysis results in Chapter 3.2.

Figure 4. Relationship of the coating microhardness with temperature

3.4. The effect of the temperature on the thickness

To further verify the influence of temperature on the coating thickness as shown in Figure 3, the curve of coating thickness and mass changing with temperature are got, shown in Figure 5.
With the temperature varying from 380℃ to 420℃, the coating thickness increases gradually, raising from 17.94μm to 66.56μm. The reasons are as follows. The sherardizing coating is formed by the diffusion of Zn and Fe atoms, as shown in Figure 1(b). According to the diffusion principle, with the increase of temperature, the diffusion coefficient of atoms increases, so that the diffusion speed of Zn and Fe atoms raises. In addition, the vacancy can act as the channel of atom diffusion, and the number of vacancy increases with the temperature, therefore the diffusion motion of Zn and Fe becomes easier [9]. As also can be seen in Figure 5, the coating mass raises with temperature. It indicates that more atoms participate in diffusion with the increase of temperature, resulting in the coating thickness increasing, which is consistent with the previous analysis.

4. Conclusions
When the sherardizing temperature varies from 380℃ to 420℃, the coating is uniform and dense. The coating is consisted of an outer region and an inner region, which formed by the diffusion of Zn and Fe atoms. The outer region refers to the FeZn10 phase and the inner region to the Fe11Zn40 phase. The outer region is thicker than the inner region. With the increase of temperature, the coating morphology changes little, but the coating thickness and mass increase slowly. The coating microhardness fluctuates around 300HV with the temperature increasing from 380℃ to 420℃.

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