

Cross-sectional observation of the intermetallic phase in a galvanized steel

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ABSTRACT

The coated zinc layer on the dual-phase steel can possess excellent anti-corrosion properties, and the continuous hot-dip process for the dual-phase steel is well known as galvanized treatment. Since the coated layer is very thin, it is very difficult to acquire a thin foil for transmission electron microscopy by the traditional twin-jet method. The focused ion beam method was used in the present study to obtain high-quality specimens for investigating the details of the microstructure in the coated layer. It was found that a fully microalloying layer exists between the zinc layer and iron matrix. The zinc-rich phases ζ and δ can be observed in the coated layer. However, the Γ_1 and Γ_2 phases could not be detected in the present study, although they could be expected in parts of lower zinc content in the coated layer.

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1. Introduction

The structure of dual-phase steel consists of martensitic phase in the ferrite matrix. Such steel has been extensively used in the automotive industry because of its high strength, good ductility, continuous yielding, high initial work hardening rate, and low yielding ratio [1,2]. However, the poor corrosion resistance of dual-phase steel as compared with stainless steel restricts the application of the former in the vehicle industry, especially in the outer panels of automobiles. Galvanized (GA) coating for dual-phase steels has been intended to improve corrosion resistance. However, few microstructure studies of GA coatings were conducted because of the difficulty of sample preparation. A focused ion beam (FIB) technique has been used to remove materials from very small and precisely located slabs, allowing preparation of cross-sectional transmission electron microscopy specimens of Zn-coated steels [3].

The GA coatings will become microalloyed with Fe present in the steel substrate due to diffusion into the coating layer, thus forming different types of intermetallic compounds [4,6,7]. Altogether, there are four intermetallic compounds of Fe and Zn, as can be inferred from the phase diagram (Fig. 1) [5]. The detailed crystal structures, lattice parameters and the possible chemical formulas of these intermetallic compounds and the pure phases are

summarized in Table 1 [8]. The objective of the present study is to investigate the microstructure characteristics of galvanized dual-phase steel.

2. Experimental procedure

A 1.8-mm thick GA steel sheet was supplied by the China Steel Corporation. Galvanizing was performed in a hot-dip continuous galvanizing line. The chemical composition and the manufacturing process for the galvanized dual-phase steel are not shown here due to concerns about intellectual property rights.

The microstructure of the Fe–Zn coating was studied by using optical microscopy, scanning electron microscopy (SEM, XL-30), and transmission electron microscopy (TEM, JEOL JSM2000). Specimens for optical metallography were etched in a solution of 5% nitric acid. TEM specimens of dual-phase steel were thinned to 0.8 mm by abrasion on silicon carbide paper and then electropolished in a twin-jet electropolisher using a solution of 5% perchloric acid, 25% glycerol, and 70% ethanol at -25°C and 50 V potential. The cross-sectional TEM specimens of Fe–Zn coatings were thinned in a focused ion beam. The Fe–Zn content of the coating layer was measured by using electron-probe microanalysis (EPMA, JEOL JXA-8200).

3. Experimental results and discussion

The optical microstructure observed in the dual-phase steel is shown in Fig. 2. The ferrite and martensite phases are composed

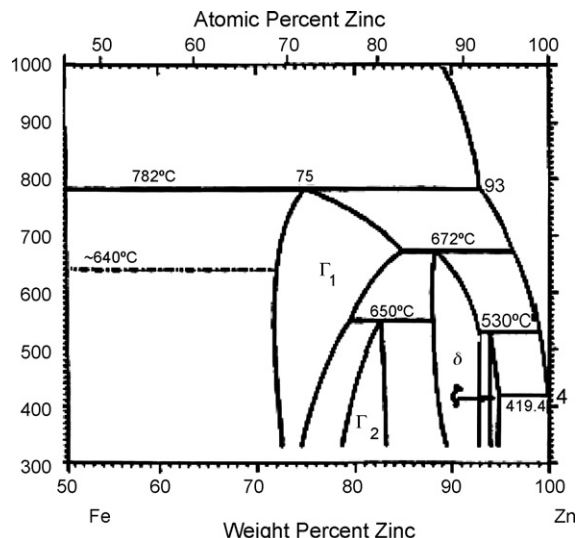
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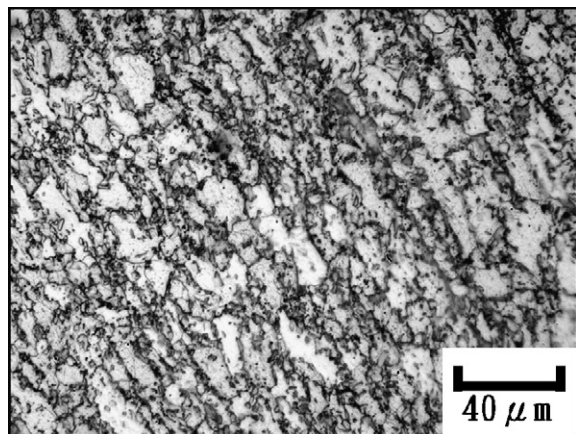
Table 1

Summarization of crystal structures, lattice parameters and the possible chemical formulas of Fe–Zn binary phases according to Ref. [8]

Phases	Formula	Crystal structure	Space group	Lattice parameters (Å)
η	Zn	Hexagonal	$P6_3/mmc$	$a = 2.67$; $c = 4.95$
ζ	FeZn_{13}	Monoclinic	$C2/m$	$a = 13.39$; $b = 7.59$; $c = 5.07$; $\beta = 127.23^\circ$
δ	FeZn_{10}	Hexagonal	$P6_3mc$	$a = 12.8$; $c = 57.6$
Γ_2	$\text{Fe}_{11}\text{Zn}_{40}$	Cubic F-lattice	F_{43m}	$a = 17.96$
Γ_1	$\text{Fe}_3\text{Zn}_{10}$	Cubic I-lattice	I_{m3m}	$a = 8.9741$
α -Fe	Fe	Cubic I-lattice	I_{m3m}	$a = 2.8665$

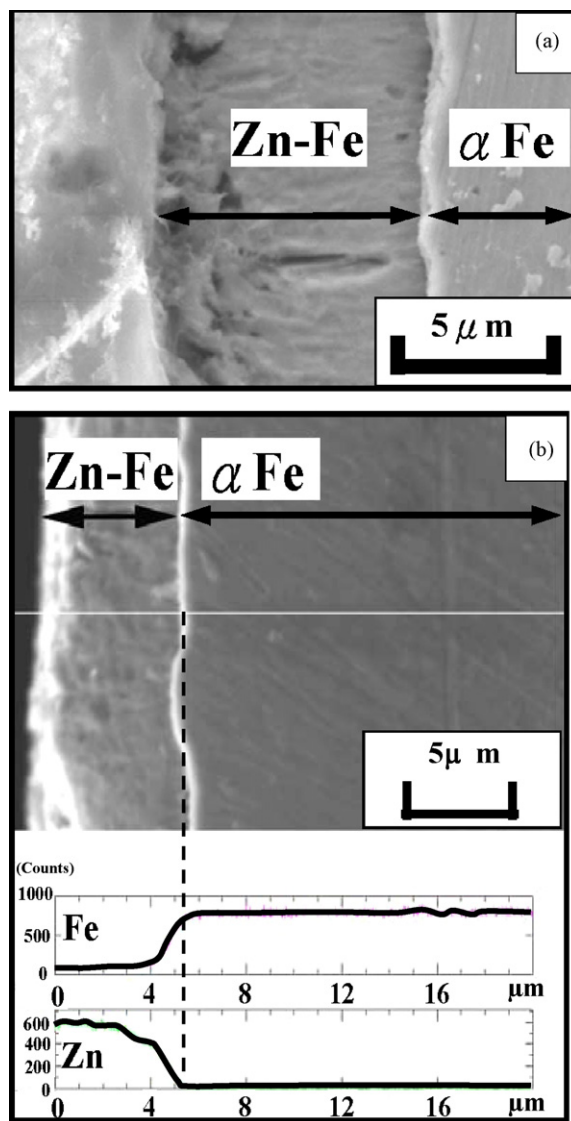
**Fig. 1.** The Fe–Zn phase diagram, from Ref. [5].

of the whole microstructure. The martensite islands are embedded in the soft ferrite matrix, thus achieving excellent mechanical properties. Smaller ferrite grains are believed to be generated by an intercritical process and can induce the continuous yielding phenomenon. The banded structure appearing in the dual-phase steel is induced by the rolling deformation. Since the ferrite microstructure would be generated by the diffusional phase transformation process at high temperature, the rejection of carbon atoms from the ferrite would partition into the surrounding austenite phase. Thus it is generally observed that the high-carbon twinned martensite phase occurs in dual-phase steel. The whole microstructure of dual-phase steel depends on the steel chemistry and manufacturing processes. According to previous studies [9,10], the optimum amount of martensite in the dual-phase steel is about 20–30%, and

**Fig. 2.** Optical micrograph of dual-phase steel substrate.

it is very important to control the whole steel-making processes to meet that requirement.

The thickness of the coated Zn layer is critical in order to avoid corrosion of the dual-phase steel. The cross-section image of the galvanized dual-phase steel and corresponding composition profile across the interface between the coating layer and the substrate are shown in Fig. 3. The thickness of the coated Zn layer is about 6 μm, a thickness believed to endow very good anti-corrosion properties. From the composition profile, it can be seen that the diffusion layer between the coated Zn layer and the iron matrix is about

**Fig. 3.** (a) SEM and (b) corresponding chemical composition profile of cross-section of dual-phase steel.

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