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Morphology and texture of high speed galvanized coatings on interstitial free steel sheet

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Abstract: The morphology and texture of zinc coatings deposited on interstitial free (IF) steel sheets were investigated by means of scanning electron microscopy (SEM) and orientation distribution function. It was shown that the microstructure of the coatings consisted of thin hexagonal platelets tilted with respect to the substrate surface. Zinc coatings exhibited low angle pyramidal {11.5} nonfiber texture component resulting from epitaxial growth via two-dimensional (2D) nucleation. The 2D nucleation was attributed to severe zinc hydroxide adsorption on the substrate surface during the nucleation stage, which can inhibit three-dimensional (3D) nucleation and promote nonfiber texture. The pyramidal texture was beneficial for plastic deformation of zinc coatings because a significant amount of resolved shear stress can be obtained when the uniaxial stress is applied.
Key words: zinc coatings; morphology; texture; deformation

1 Introduction

High speed galvanized steel sheets widely used in automotive applications are currently subjected to large deformations during production processes[1−4] and therefore, in addition to the substrate ductility, the plastic formability of the coating would be necessary[5−6]. So there is an increasing interest to investigate the morphology and texture of the coatings, which influences the formability significantly.

The morphology and texture of zinc deposits can be explained by the mechanism of nucleation and growth[2]. Nonfiber pyramidals {11.5} and {11.6} texture can be promoted by the epitaxial growth via 2D nucleation and bunching growth, meanwhile, the {00.2} basal texture can be promoted during the growth of 3D nuclei. Zinc hydroxide layer suppression mechanism for zinc deposition was developed by HIGASHI et al[7] previously, which was confirmed by other researchers[2, 8−9] later. Zinc hydroxide adsorption which prevents 3D nucleation and increases 2D nucleation frequency was described in Refs.[2, 8−9]. FISHER[10] described that the adsorbed hydrogen in the electrodeposition can prevent direct incorporation of adions into the microsteps, which increases 2D nucleation frequency, and therefore encourages the lateral bunching growth of zinc.

RANGARAJAN et al[5] reported that {00.2} texture is not an ideal orientation for plastic deformation, as the resolved shear stress on the basal planes is zero. Meanwhile, {11.2} texture which is a favorable orientation for basal plane slip can be obtained through adjusting electroplating process.

The purpose of this work is to observe the morphology and texture of the zinc coatings on interstitial free (IF) steel sheets in detail and investigate the influence of the high speed galvanizing process on the morphology of zinc layers. Furthermore, the effects of texture of the zinc coatings on the deformation behavior of the high speed galvanized IF steel sheets are also discussed.

2 Experimental

A commercial cold rolled IF steel sheet with a thickness of about 0.75 mm was used as substrate. Galvanized steel samples were taken from the production line of an industry after cutting to a size of 20 mm×20 mm. High speed galvanizing equipment was mounted vertically to take advantage of the gravitational flow.

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Tanks at the bottom of the equipment were filled with zinc sulphate solution, the circulation of which was achieved by a pump. The running velocity of steel sheets was 120−180 m/min and the applied current density was 60−100 mA/cm^2. The anode used was titanium coated with iridium oxide.

Cryogenic fracture technique was used to study the cross section of the coatings. The samples were immersed in liquid nitrogen for about 5 min, and then mechanical impact was applied on them to obtain the fracture plane of the zinc coatings. JEOL JSM−7001F field emission scanning electron microscope was used to observe the morphology and cross section of the investigated deposits. The macro-textures were measured using an X'Pert MRD-type X-ray diffractometer by back reflection method, using Co K_α radiation. Four incomplete pole figures {00.2},{10.1},{10.2} and {11.2} were measured for the coatings, and they were used to calculate the orientation density function (ODF) by two-step method. For the substrate, three incomplete pole figures {110},{200} and {211} were measured. All the results were presented in the constant φ_2 sections under Bunge's notation system.

3 Results and discussion

3.1 Morphology observation

Figure 1 shows the SEM image of the zinc coating surface on the galvanized steel sample. The coating exhibits the morphology of thin hexagonal platelets which are tilted with respect to the substrate surface with several variants. Sets of parallel ledges which were identified as edges of the zinc basal planes and resulted from the epitaxial growth of zinc were shown in relief on the surface. Cryogenically fractured morphology of the galvanized steel sample is shown in Fig.2. The ridges represent parts of the hexagonal platelets which were parallel to each other and arranged compactly.

It is suggested that the surface morphology is related to the epitaxial growth of zinc which develops through 2D nucleation and bunching growth and plays an important role in crystal growth under industrial conditions[2, 11]. 2D nucleation generates a new plane on a substrate surface, and then adsorbed zinc atoms incorporate one after another into microsteps or kinks of crystal surface of the 2D nuclei. As the edge energy per atom is always higher than the surface energy, the generation of microsteps can decrease the total surface free energy, and meanwhile, the existence of microsteps promotes the epitaxial growth of zinc[2, 11−12].

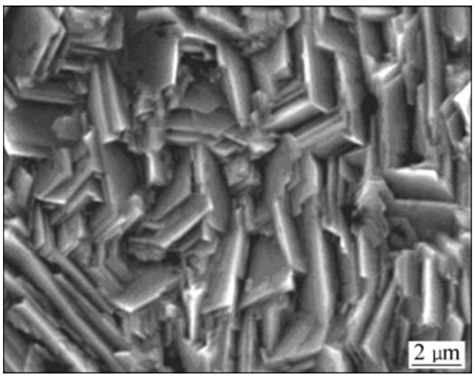

Fig.1 Surface morphology of zinc coating

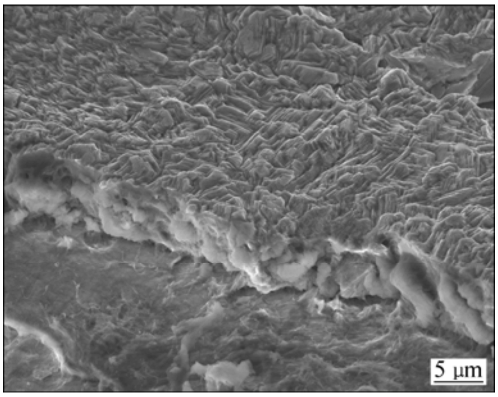

Fig.2 Cryogenically fractured morphology of zinc coating

For the high speed galvanization, cations near the cathodic plates can be effectively supplemented during the electrodeposit process due to the flow of electrolyte, so high current density up to 60−100 mA/cm^2 can be used. The hydrogen evolution rate is initially high during zinc electrodeposition, which leads to rapid formation of a zinc hydroxide layer in the solution near the cathode. Hydrogen can be carried away during the high speed relative motion between the steel sheet and electrolyte, while the adsorbed zinc hydroxide which covers the entire electrode surface acts as a blocking adsorbate to inhibit the 3D nucleation through bouncing the active sites for nucleation[2, 10]. 3D nucleation can develop non-epitaxial component through the formation of a new crystal[2, 13]. The surface morphology results from the competition between 2D nucleation and the bunching of the initial monoatomic layers[11−12]. The promotion of 2D nucleation and the inhibition of 3D nucleation lead to the titled platelets eventually.

3.2 Texture observation

Figure 3 shows the cross section of the ODF at φ_2=45° of IF steel used as the substrate. From the textural study of the substrate steel, it is found that reasonably strong gamma (γ) fibers are present. The presence of sharp γ fibers indicates satisfactory formability of the steel substrate. Meanwhile, increasing {111} texture component of the substrate surface results in increasing intensity of low angle pyramidal planes in the coating parallel to the substrate surface[10, 14].

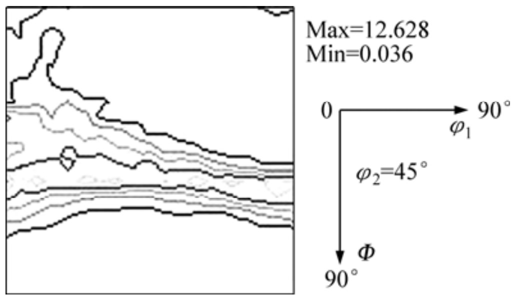

Fig.3 Cross section of ODF of substrate IF steel sheet at φ_2=45° (Levels=2, 4, 6, ⋯)

Figure 4 shows the cross sections of the ODF of zinc layer at φ_2=0° and φ_2=30°. The selected cross sections of the ODF can reveal the texture components sufficiently. From Fig.4(a), a sharp non-fiber texture component {11.5} is detected (Φ=35°). According to the orientation levels of {11.5}⟨uv.w⟩ texture components presented in Fig.5, the peak intensity (about 15.2) at A position is near {11.5}$\langle\bar{2}\bar{3}.1\rangle$ (φ_1=70°, Φ=35°). Epitaxial growth of zinc can construct the pyramidal texture component. The absence of {00.2} basal fiber texture, which is known to exhibit the best corrosion resistance[2, 15−16] can be verified by the cross section of the ODF at φ_2=0°, as shown in Fig.4(b).

To understand the influence of the texture upon the surface morphology of zinc coatings, a schematic description of {11.5} nonfiber texture is illustrated in Fig.6(a). There is a certain angle θ between the basal planes of zinc nucleus and the surface of the substrate.

The nucleus grows up to lamellar crystals through epitaxial growth, so sets of tilted platelets were detected

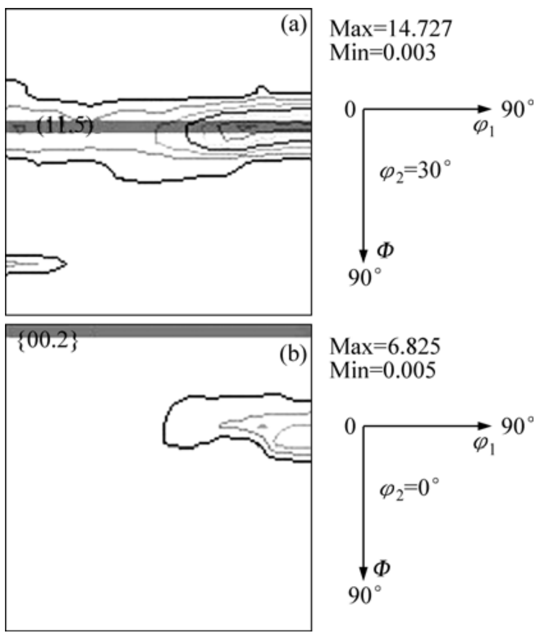

Fig.4 Cross sections of ODF of electrogalvanized coating (Levels=2, 4, 6, ⋯): (a) φ_2=30°; (b) φ_2=0°

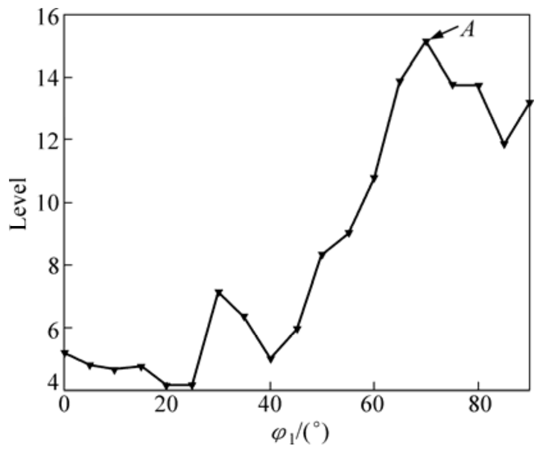

Fig.5 Orientation levels of {11.5}⟨uv.w⟩ texture components

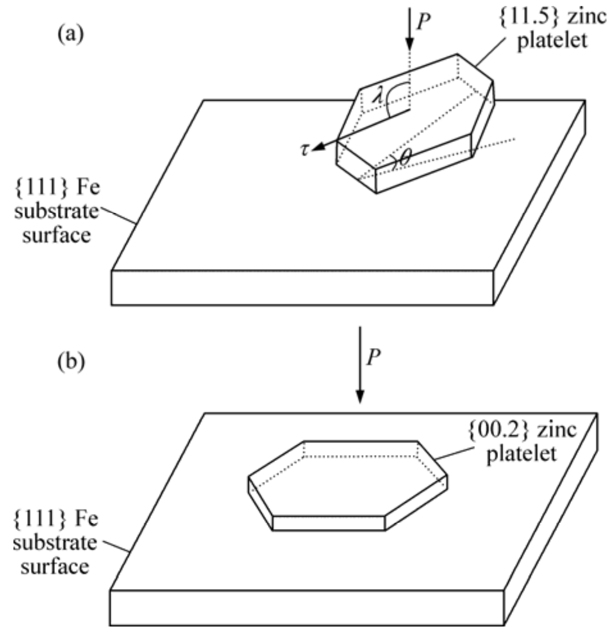

Fig.6 Schematic illustration of two different types of coating morphology: (a) {11.5} texture; (b) {00.2} texture

in the morphology observation. The nonfiber texture is formed due to the epitaxial growth resulted from substrate orientation influence. The epitaxial growth proceeds via 2D nucleation following bunching growth, which can generate new steps and promote the nonfibers {11.5} and {11.6} texture components[12]. Besides that, due to the inhibition of 3D nucleation which enhances non-epitaxial growth and promotes fiber texture components, {00.2} basal texture was not detected, although it has lower surface energy[2].

Relative work reported some similar results. {11.5} and {11.6} nonfibers were obtained on electropolished steel substrate by RAEISSI et al[12]. VASILA-KOPOULOS et al[17] used X-ray diffraction patterns to calculate relative texture coefficients for different planes of zinc deposited and detected some {11.4} orientation on chemically polished steel substrates.

For the applications in automobile, galvanized sheets are exposed to large deformations during production process, so in addition to the substrate ductility, the optimum formability of the coating would be necessary[6]. In the hexagonal phase, the slip system is {00.2}⟨11.0⟩. So the angle between the basal planes of zinc crystals and the surface of the substrate determines the deformation behaviour of the zinc coatings[5−6] to a large extent. For the {11.5} texture of the zinc platelets, the basal planes of the zinc coatings are inclined at the angle θ of about 33.2° with respect to the substrate surface. The resolved shear stress τ can be calculated using the following equation:

$$\tau = \frac{P}{S}\cos\lambda \tag{1}$$

where P is the applied uniaxial force; S is the surface area of basal plane and λ is the angle between the applied uniaxial force and the slip direction.

For the coatings under the applied stress, a remarkable amount of resolved shear stress exists on these planes and then zinc grains can slip and rotate, so plastic flow is facilitated. Furthermore, slipping and rotation of zinc grains can yield good substrate coverage as the coatings are subjected to high strains[5]. For the common {00.2} texture, the basal planes of the coatings are parallel to the substrate surface (Fig.6(b)), and the resolved shear stress on these planes is zero as the angle λ is 90°. It is difficult to accommodate deformation by gliding[5]. Therefore, with the applied stress parallel to the c-axis of zinc crystal, mechanical twinning with extended variety serves as the main deformation mode[18−19]. Even so, for drastic machining deformation of zinc coatings, the contribution of mechanical twinning is inconspicuous. As a result, besides the high efficiency, the favorable formability of coatings due to the pyramidal nonfiber texture is also a significant reason for wide application of high speed galvanization.

4 Conclusions

1) The morphology of high speed galvanized coatings on IF steel sheet consists of a series of overlapping hexagonal platelets which are tilted with respect to the substrate surface. High speed galvanization leads to the rapid formation of zinc hydroxide layers. Adsorbed zinc hydroxide on the substrate surface can promote 2D nucleation and inhibit 3D nucleation, then result in the ridges morphology.

2) The predominant texture of high speed galvanized coatings on IF steel sheets is {11.5} pyramidal nonfiber and the peak intensity is located near {11.5}⟨$\overline{2}\overline{3}$.1⟩. The {111} texture of substrate benefits the formation of the pyramidal texture of the zinc layers. Besides, the nonfiber texture formation can be explained by the epitaxial growth via 2D nucleation following bunching growth.

3) With {11.5} nonfiber texture of zinc layers, the angle between the basal planes of zinc crystals and the substrate surface is about 33.2°. Superior plastic deformation of the coatings can be obtained due to high resolved shear stress when subjected to applied uniaxial stress.

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IF 钢基板高速电镀锌的微观形貌和织构

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摘 要：采用高速电镀技术在无间隙原子钢(IF 钢)基板上镀锌，借助扫描电镜和取向分布函数研究镀锌层的微观形貌和织构。结果表明，镀锌层由一系列倾斜于基体表面紧密排列的六方形片晶组成，初始电沉积时基体表面氢氧化锌的大量吸附抑制锌的三维形核，二维晶核的外延生长以及 IF 钢基板的{111}纤维织构促进镀锌层{11.5}锥形非纤维织构的形成。镀锌层呈锥形织构时，片晶的滑移面与基体表面呈一定角度，保证镀层在受到轴向应力时产生一定量的分切应力，从而有利于自身的塑性变形。

关键词：镀锌层；微观形貌；织构；变形

(Edited by FANG Jing-hua)