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Relationship between (00.2) and (20.1) texture components and corrosion resistance of hot-dip galvanized zinc coatings

H. Asgari[a,b,*], M.R. Toroghinejad[a], M.A. Golozar[a]

[a] Department of Materials Engineering, Isfahan University of Technology, Isfahan 8415683111, Iran
[b] Young Researchers Club, Arak, Iran

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ABSTRACT

Hot-dip galvanized coatings have attracted increasing interest from the automobile industry and steel producers because of their excellent corrosion resistance. Texture is an important factor, which affects the coating properties. Chemical composition of the zinc bath can strongly influence the texture of hot-dip galvanized coatings. In this study, lead content of the zinc bath was changed from 0.01 to 0.11 wt.%. Specimens were prepared from zinc baths with different lead content and their texture was evaluated using X-ray diffraction. Corrosion behaviour of the specimen was analyzed by Tafel extrapolation and salt spray tests. Cross-sectional studies were performed using optical microscopy. Also, the spangle size of the specimens was determined using line intercept method. From the experimental results it was found that (00.2) basal plane texture component would be weakened by increasing the lead content of the zinc bath and coatings with strong (00.2) texture component have better corrosion resistance than the coatings with weak (00.2) texture component. In addition, the increase in lead content of the zinc bath would strengthen the (20.1), (10.3) and (10.0) texture components and stronger (20.1) high angle pyramidal plane texture component would decrease the corrosion resistance of the coating. Furthermore, spangle size and number of dull spangles would be increased by increasing the lead content of the zinc bath. Finally, it was found that increasing the lead content of zinc bath has no effect on the phases detected in corrosion products.

1. Introduction

In a large number of continuous hot-dip galvanizing lines, lead is usually incorporated into the zinc bath. This addition not only causes an increase in the bath fluidity and a decrease in its surface tension but also, in small concentrations (0.04–0.2 wt.%) improves the zinc coating uniformity and its adhesion to steel sheet (Cameron et al., 1965). However, this also induces the excessive growth of the zinc crystals and dendritic type solidification in the form of spangles (Sere et al., 1999). Spangles are believed to grow from a nucleus and with an important solute segregation, with one of the most common structures being the six-pointed star or snowflake (Cameron and Harvey, 1967; Jafery et al., 1980; Fasoyinu and Weinberg, 1990). The spangles are the result of dendritic solidification of zinc (Helwing, 1981). Spangle size is influenced by cooling conditions during solidification. The three surface finishes commonly produced are regular spangle, minimum spangle and extra-smooth spangle (Marder, 2000). With preferred nucleation sites at the liquid Zn/substrate interface, growth of Zn spangles occurs in three stages including (1) the initial growth stage (0.1 s) involves sideways growth of Zn basal

* *Corresponding author*. Tel.: +98 861 2776316.
E-mail address: asgari.ha@gmail.com (H. Asgari).
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plane parallel to the interface in [1 $\bar{1}$ 0 0] growth direction. The entire steel surface is covered by a solid layer of zinc dendrites, whereas the surface remains liquid; (2) the second stage involves slow thickening of the solid zinc grain which is dependent on grain orientation; (3) the third stage, or continuous thickening of the zinc grain, causes solute enrichment of the remaining liquid and finally Pb precipitation between Zn dendrite arms (Strutzenberger and Faderl, 1998). Large spangles are generally associated with solute additions to the galvanizing bath and Pb, at concentrations greater than 0.04 wt.%, is the solute generally added to molten Zn to produce spangles (Fraley, 1994).

The preferred crystallographic orientation (texture) depends strongly on external factors such as cooling rate gradient, surface condition of steel substrate during the coating solidification process and bath chemical composition (Chang and Shin, 1994). Concerning the coating corrosion resistance, this depends in particular on the zinc layer chemical composition and also is affected by the crystallographic orientation.

When a metal is exposed to a corrosive environment, the corrosion resistance of each grain varies because of the difference in the binding energy of atoms between the crystallographic planes. According to Scully, the total energy involved in the breaking of the bonds and the subsequent dissolution of atoms is higher for the crystallographic planes, which have a higher number of nearest neighbor atoms. Thus, the close packed planes, or low-index planes, are known to be more resistant to dissolution because of the higher binding energy of the surface atoms (Scully, 1990).

The aim of this work is to assess the effects of different concentrations of lead in the zinc bath on some texture components of hot-dip galvanized coatings deposited on steel sheets. In addition, the effects of (00.2) and (20.1) texture components on corrosion resistance as well as spangles of hot-dip galvanized zinc coatings is analyzed.

2. Experimental procedure

2.1. Materials

All the tests were carried out three times with commercially available JIS G3302 hot-dip galvanized steel sheets and the average of the results considered as the final report. Also, production conditions such as rolling finishing temperature, coiling temperature, cold work percentage and annealing conditions are the same for all the steel sheets used in this study. In this research work, lead content of the zinc bath was changed from 0.01 to 0.11 wt.%. Production parameters and chemical composition of the steel substrate are shown in Tables 1 and 2, respectively. As it can be seen in Table 1, the variations of Al and Fe wt.% are very small and negligible and thus, they are considered to have no effect on texture and corrosion resistance of the specimens. The thickness of coating for all the specimens was about 44 μm. Analyzing of chemical composition of the zinc bath was performed using atomic absorption.

Table 2 – Chemical composition of steel sheets (Grade, JIS G3302)

%C	0.038
%Ti	0.001
%S	0.005
%Mo	0.002
%P	0.007
%V	0.001
%Si	0.009
%Al	0.048

2.2. Microstructure study

Cross-sections of coatings were studied using optical microscopy and conventional metallography methods. Because of high sensitivity of zinc to water, absolute alcohol was used for grinding and polishing of specimens. Also, polishing was performed along the intermetallic layers and grinding was carried out employing soft sand papers (2400 or 4000). The composition of coating layers was determined using EDS analysis.

2.3. Texture determination

The crystallographic orientation of the coatings was determined using X-ray diffraction (Philips XL Model 30, Cu Kα radiation, step size of 0.03° and counting time of 1 s). A 2θ scan was performed between 20° and 140° and the integrated intensities of several reflections were determined, these are termed $I_{(hk.l)}$. It should be noted that integrated intensities require background subtraction. Each $I_{(hk.l)}$ is normalized by dividing it by its structure factor or random intensity, $I^0_{(hk.l)}$, giving $I^n_{(hk.l)}$. Values of $I^0_{(hk.l)}$ were obtained from powder zinc pattern. It should be mentioned that nine values of $I^n_{(hk.l)}$, representing nine planes, were calculated but in this paper, only four values of $I^n_{(hk.l)}$ are presented.

Table 1 – Production parameters of specimens

Specimen	Chemical composition of the zinc bath			Jet wiper distance from sheet surface (mm)	Sheet thickness (mm)	Zinc bath temperature (°C)	Strip-entry temperature (°C)	Galvanizing line speed (m/min)
	%Pb	%Fe	%Al					
A	0.010	0.023	0.195	100	0.5	461 ± 1	467 ± 1	100
B	0.045	0.027	0.191					
C	0.065	0.021	0.188					
D	0.110	0.023	0.190					