

Corrosion Behavior of Electrogalvanized Steel Plated Under Static & Rotational Conditions

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The effect of plating conditions, such as current density and the rotation of specimens, on the corrosion resistance of pure zinc coatings was studied. The corrosion rates were determined by weight loss technique, through atomic absorption spectrophotometry and electrochemical measurements. The results indicate that a minimum corrosion rate of 18.9 *mpy* was obtained at a current density of 200 mA/cm² and rotational speed of 500 rpm. The deterioration in deposit morphology of Zn coatings was examined by scanning electron microscope. The results were in agreement with the corrosion rate measurements. A simplified energy study for the process was made, indicating that total energy consumption at 200 mA/cm² and 3.0 min is 2.0 and 4.2 kwh/kg for static and rotated specimens, respectively.

Coating is the most common means of combating corrosion of metals. It works on the principle of completely separating the metal from the cause of the corrosion, or slowing the reaction that may occur between the metal to be protected and the corrodent. Zinc is the most important coating metal for iron and steel. The success of zinc can largely be attributed to ease of application, sacrificial nature and low cost. The production rate of the zinc coating process is considered an important factor from the economic point of view; it needs to be maximized without sacrificing the quality of the coating. Accordingly, a primary thrust in the industry is directed to increasing the operating current density without sacrificing metal quality. The latter is most often gauged in terms of deposit smoothness, because rough, irregular growth occurs when the current density becomes excessive.¹⁻⁴

Recent theoretical and applied studies, ranging from bench-scale to full-sized pilot cell, have shown the impor-

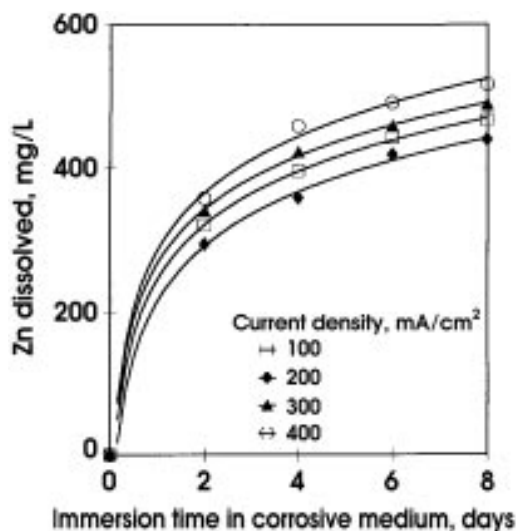


Fig. 1—Effect of current density on the corrosion resistance of Zn coatings in 3.5 wt percent NaCl at 0 rpm.

Table 1
Chemical Composition of Mild Steel

(Wt percent)										
C	Si	Mn	P	S	Ni	Mo	As	Pb	Sb	Fe
0.09	0.09	0.57	0.03	0.01	0.02	0.01	0.01	0.01	0.01	Bal.

tance of enhanced mass transfer in improving the performance of many electrolytic systems, whether by means of optimized alternative cell design or improved forced convection in existing plants.

The present research investigated the effect of current density on the corrosion rate of Zn-coated steel at room temperature. The research also studied the effect of rotation on zinc coating quality. The corrosion rates were measured by weight loss and potentiodynamic techniques. The morphologies of Zn coatings were examined by scanning electron microscope (SEM).

Experimental Procedure

The plating process was employed on mild steel rods 4 mm in diameter. The chemical composition of the mild steel used is given in Table 1. A 250-mL glass container was used as an electroplating cell. The anode had a cylindrical shape and was made from pure zinc. The steel cathode was fixed in the center of the container by a holder. The composition of the zinc electrolyte and the corresponding plating conditions are shown in Table 2.

Before plating, the steel rods were degreased and polished electrochemically, then rinsed with tap and distilled water. The substrate was isolated with Teflon[®] tape, except 5 cm² left for zinc plating. Corrosion measurements were carried out by immersing the substrates in 3.5 wt percent NaCl solution, used as a corrosive medium. Atomic absorption spectroscopy (AAS) technique was used to measure the amount of zinc dissolved during the time of immersion. The values of zinc concentration obtained were converted to *mpy*.

Table 2
Zinc Electrolyte & Plating Conditions

Composition	
ZnSO ₄ · 7H ₂ O	442.4 g/L
Na ₂ SO ₄	26.5 g/L
CH ₃ COONa · 3H ₂ O	13.8 g/L
NaCl	1.0 g/L
Conditions	
Current density	100–600 mA/cm ²
Specimen rotational speed	0–700 rpm
Plating time	3.0 min
Temperature	25 °C
pH	4.0

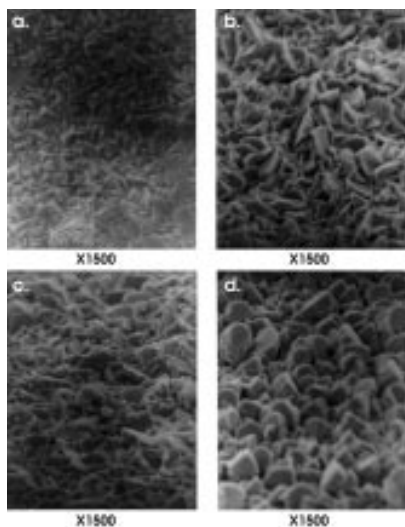


Fig. 2—SEM photographs for pure Zn coatings at: (a) 100 mA/cm²; (b) 200 mA/cm²; (c) 400 mA/cm²; (d) 600 mA/cm².

The polarization measurements were made with a potentiostat. A scanning electron microscope was used to examine the morphology of zinc coatings on the steel substrates.

Results and Discussion

Figure 1 shows the effect of current density on the corrosion resistance of zinc coatings immersed in 3.5 wt percent NaCl solution. The results obtained show that increasing current density enhances zinc dissolution. For ex-

ample, the concentrations of Zn resulting from corrosion after 192 hr (8 days) immersion time are 468, 443, 490 and 515 mg/L for current densities of 100, 200, 400 and 600 mA/cm², respectively. Current density of 200 mA/cm² is considered an optimum value to study the effect of rotation on the corrosion rate and morphology of coatings, because at higher current densities, Zn corrodes more rapidly. In addition, coatings obtained at lower current density, such as 100 mA/cm², also had greater corrosion rates. Visual examination of the surface of zinc coatings shows changes in texture, where they tend to be rough, porous and powdery as the current density increases. The micrographs shown in Fig. 2 indicate that lower current densities give finer, more compact coatings. The high loss of zinc resulting from the increase in plating current density could be attributed to the change in morphology of the deposit surface. It was recognized that deposit quality deteriorates quickly at current densities approaching the limiting values; consequently, corrosion rate is increased. Current density is considered an important factor in increasing the production rate of zinc coatings. A balance must be reached, therefore, between the production rate and the corrosion rate.⁵

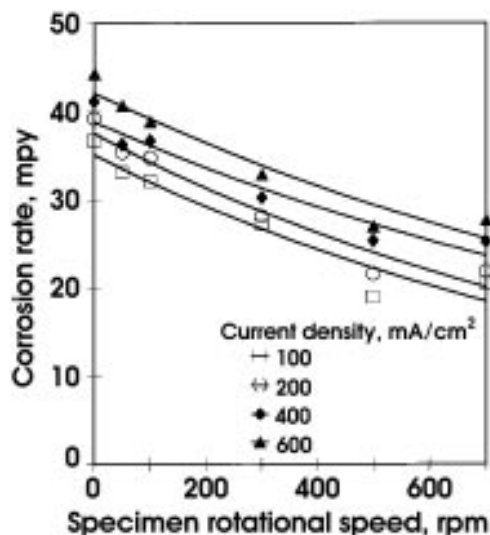


Fig. 4—Corrosion rate vs. specimen rotational speed at several current densities.

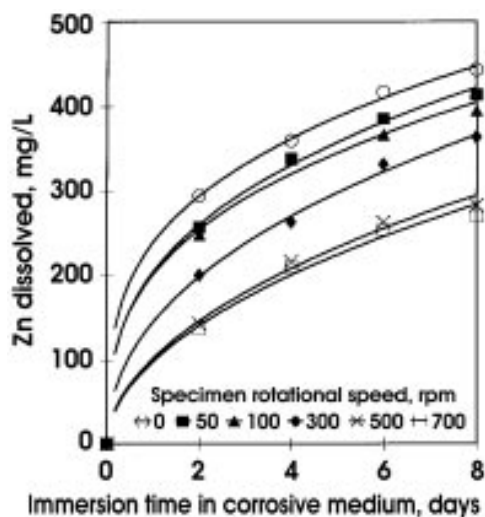


Fig. 3—Effect of specimen rotational speed on corrosion resistance of Zn coatings in 3.5 wt percent NaCl at 200 mA/cm².

Figure 3 shows the effect of specimen rotational speed on the corrosion resistance of zinc immersed in 3.5 wt percent NaCl solution. The results obtained indicate that increasing the rotational speed of a specimen decreases the dissolution of zinc in a corrosive medium. For example, plated Zn at a current density of 200 mA/cm², immersed for 192 hr in NaCl solution, gives zinc concentration of 443, 398 and 281 mg/L for 0, 100 and 500 rpm, respectively. Figure 4 shows the relationship between the corrosion rate in *mpy*, calculated from the total area under the curves of zinc dissolution with several plating conditions and rotational speeds. In all the current densities examined, the increase of specimen rotational speed decreases the corrosion rate. For example, the corrosion rate drops from 31.5 to 18.9 *mpy* as the rotational speed increases from 100 to 500 rpm at a current density of 200 mA/cm². The electrochemical technique supports the weight loss results measured by AAS. Figure 5 shows the polarization measurements carried out in 1-percent NaCl solution. The corrosion current density, I_{corr} , decreased from 9.3×10^3 to 3.9×10^3 nA/cm² as the specimen rotational speed increased from 0 to 500 rpm. It was also noticed that 14 mV difference between the equilibrium potentials, E_{corr} , was a result of rotation. This change is in the noble direction.

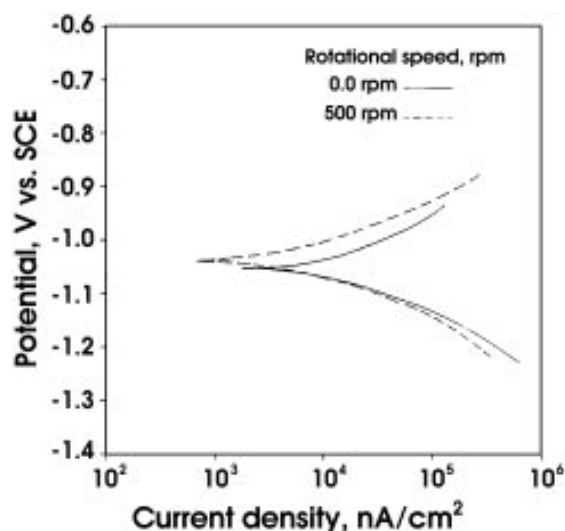


Fig. 5—Polarization curve for pure Zn coatings in 1-percent NaCl.

Table 3
Effect of Plating Conditions on the Corrosion Rate (mpy)
& Power Consumption (kwh/kg)

Plating Conditions		Specimen Rotational Speed			
		0.0 rpm		500 rpm	
Current density mA/cm ²	Plating time min.	Corrosion rate (mpy)	Power consumption (kwh/kg)	Corrosion rate (mpy)	Power consumption (kwh/kg)
100	6.0	39.5	1.7	22.4	4.0
200	3.0	36.5	2.0	18.9	4.2
400	1.5	45.1	2.9	26.9	6.0
600	1.0	49.8	4.2	29.9	7.2

The scanning electron micrographs for zinc coatings (plated at 200 mA/cm²) are shown in Figs. 6a and 6b for static and rotated specimens, respectively. The zinc facets in the case of rotation are smaller and more compact than in static condition. The morphology of these coatings was examined also after immersion in 3.5 wt percent NaCl solution for 48 hr. The resulting SEM photographs are shown as Figs. 7a and 7b. It was also observed that the dissolution of Zn for rotated specimens is less than that for the static condition. Therefore, the morphology studies agree also with the corrosion measurements.

The increase of specimen rotational speed enhances the connective mass transfer and decreases the diffusion layer thickness. As a result, the limiting current density for zinc electrodeposition would increase. This suggests carrying out the coating process at a current density not exceeding a certain fraction of the limiting value. Consequently, a smooth uniform deposit with regular growth is obtained.⁶⁻⁸

Power Consumption

Table 3 represents the results of simplified power consumption calculations for several plating conditions, for both static and rotated specimens. The study indicates that minimum power consumption per kg coat is obtained at a current density of 100 mA/cm² and plating time of 6 min. A wattmeter totaled the power consumed in mechanical rotation of specimens. Nevertheless, the minimum rate of corrosion is

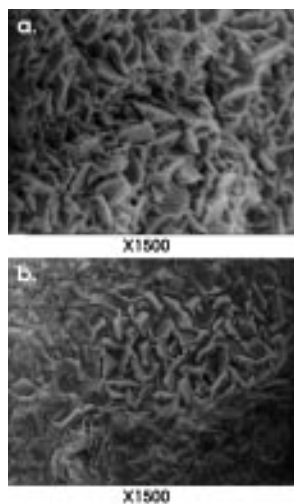


Fig. 6—SEM photographs of pure Zn coatings plated at: (a) 0 rpm; (b) 500 rpm.

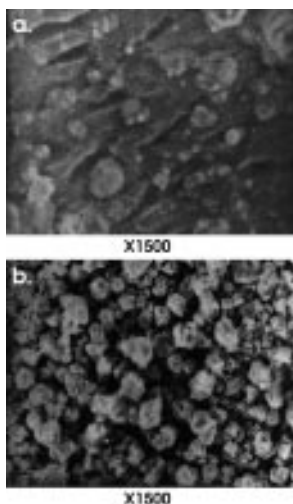


Fig. 7—SEM photographs of pure Zn coatings plated at: (a) 0 rpm; (b) 500 rpm; after immersion in 3.5 wt percent NaCl for 48 hr.

obtained at 200 mA/cm² and 3 min in both the static and rotated conditions. It is important to realize that, in both conditions, the weight of zinc coatings is the same and equal to 120 g/m². The rate of production of zinc coatings, using plating conditions of 200 mA/cm² and 3.0 min, is twice the case of 100 mA/cm² and 6.0 min. From the point of production and corrosion resistance, therefore, it is preferable to carry out the coating process at 200 mA/cm²

and 3.0 min. This can be applied on both the static and rotated conditions. The results in Table 3 indicate that power consumption doubles when specimens are rotated during plating. Although rotation was proven effective in improving the deposit quality and corrosion resistance, the production cost is expected to double. In addition, improving mass transfer by means of stirring is recommended and needs more study. Moreover, improving the corrosion resistance by changing bath composition, by alloying or addition of metallic additives, is also an attractive approach.^{9,10}

Findings

Plating current density of 200 mA/cm² offers the minimum corrosion rate for plating zinc on steel rods in both static and rotated conditions. Rotational speed of 500 rpm provides great enhancement in corrosion resistance and coating quality. The corrosion rate drops from 36.5 to 18.9 mpy when the rods are rotated at 500 rpm, indicating 50 percent improvement in corrosion resistance. The total power consumption at 200 mA/cm² and 3.0 min are 2.0 and 4.2 kwh/kg for both static and rotated conditions, respectively.

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