Electrodeposition of Zn-Cd Binary Alloy Films from Gluconate Salt Solutions

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Zinc-cadmium (Zn-Cd) binary alloy films have been galvanostatically electrodeposited on mild steel surfaces from gluconate solutions containing $ZnSO_4$, $CdSO_4$, sodium gluconate and gelatine (pH~4.5) under different electrodeposition conditions, *i.e.,* bath composition, temperature and current density. The effect of these parameters on the potentiodynamic cathodic polarization curves, cathodic current efficiency, deposit composition and throwing power of the baths has been investigated. It was found that the electrodeposition process of Zn-Cd alloy is normal, as opposed to anomalous. Deposition of cadmium (the more noble component) is under diffusion control while zinc is under kinetic control. The cathodic current efficiency of co-deposition is high but less than 100%. The anodic linear stripping voltammetry for Zn-Cd alloy deposited potentiostatically on a platinum surface involves two peaks which correspond to the dissolution of zinc and cadmium, respectively. The throwing power of the bath is low and improved by increasing the metal content in the bath.

Keywords: *Zn-Cd alloy, electrodeposition, anodic linear stripping, throwing power, gluconate solutions.*

Introduction

Zinc alloy electrodeposition has been of interest because such alloys provide better corrosion protection than unalloyed zinc coatings.[1-6] Among these alloys are Zn-Cd alloys which have been investigated by a few workers who studied different baths and operating conditions.[7-10] Colin and Young[10] studied the electrodeposition of Zn-Cd alloys from acidic sulfate baths. The authors found that increasing the temperature enhanced the cadmium content of the alloy deposit. The zinc content of the alloy increased with increasing current density and acid content in the bath. Electrodeposited Zn-Cd alloys composed of 45 - 55% cadmium were most resistant to attack by NaCl solutions.

Anodic linear stripping voltammetry (ALSV) can provide useful information about the phase composition of binary electrodeposited alloys.[11-13] The technique was found to be very sensitive to the type of alloy. The ALSV responses for binary eutectic alloys such as Zn-Cd alloys exhibit two peaks corresponding to dissolution of the pure metals.[11]

The objective of the present work is to study the electrodeposition of binary Zn-Cd alloys from gluconate baths (pH~ 4.5). Sodium gluconate is cheap, non-toxic and environmentally-friendly. An attempt was made to determine the phase composition of the alloys by the analysis of ALSV results. An attempt was also made to elucidate the throwing power and throwing index of these baths.

Experimental

In the current work, all solutions were freshly prepared from Fluka grade chemicals and doubly-distilled water. The numbers and chemical composition of these baths and operating conditions (cathodic current density, temperature and pH) are given in Table 1.

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For electrodeposition measurements, a mild steel sheet cathode and platinum sheet anode, both of dimensions (2.5 × 3.0 cm) were used. The plating cell was a rectangular Perspex trough (10 × 3 × 2.5 cm) provided with vertical grooves on each of the side walls to fix the electrodes. Before each run, the mild steel cathode was subjected to mechanical polishing with various grades of emery paper (600 up to 1200) followed by degreasing with acetone, washed with distilled water, dried and weighed. At the end of deposition (15 min) the cathode was withdrawn, washed with distilled water, dried and weighed. The zinc and cadmium composition of the deposited alloy was determined by using inductively-coupled plasma atomic emission spectroscopy (ICP - AES) model Plasma 400. Using the resultant analysis, the cathodic current efficiency (CCE) of the deposited alloy was calculated by a recommended method.[14]

The potentiodynamic cathodic polarization curves were measured in the rectangular cell containing mild sheet and platinum sheets as working and counter electrodes, respectively. A saturated calomel electrode (SCE) was used as a reference electrode. The reference electrode was connected to the working electrode via a bridge provided with a Luggin-Haber tip and filled with the solution under test. The tip was placed very close to the electrode surface. Polarization measurements were conducted using an EG&G 273A potentiostat / galvanostat, which was connected to a computer.

The throwing power (*TP*) of the solution was measured using the rectangular cell with one platinum anode placed between two parallel steel cathodes where the ratio of the far to the near distance was 5:1. The *TP* percentage was calculated from Field's formula,[15]

$$TP\% = \frac{(L - M)}{L + M - 2)} \times 100 \qquad (1)$$

where L is the current distribution ratio or linear ratio (5: 1) and M is the metal distribution ratio of the near to the far cathode position. In some cases, the values of M were mea-

Table 1

The chemical composition of the zinc, cadmium and Zn-Cd binary alloy electrodeposition baths of this study (pH = 4.5)

Bath No.	$CdSO_4 \cdot 8H_2O$ (g/L)	$ZnSO_4 \cdot 7H_2O$ (g/L)	Gelatin(g/L)	Sodium gluconate (g/L)	Potassium sulfate (g/L)	Temp. (°C)	Current density (A/dm^2)
1: Zn-Cd	5	50	1	10	10	25	0.33
2: Zn-Cd	5	50	1	10	—	25	0.33
3: Zn-Cd	5	25	1	10	—	25	0.33
4: Cd	5	—	1	10	—	25	0.33
5: Zn-Cd	5	75	1	10	—	25	0.33
6: Zn-Cd	5	100	1	10	—	25	0.33
7: Zn	—	50	1	10	—	25	0.33
8: Zn-Cd	2	50	1	10	—	25	0.33
9: Zn-Cd	8	50	1	10	—	25	0.33
10: Zn-Cd	10	50	1	10	—	25	0.33
11: Zn-Cd	5	50	0.5	10	—	25	0.33
12: Zn-Cd	5	50	1.5	10	—	25	0.33
13: Zn-Cd	5	50	2	10	—	25	0.33
14: Zn-Cd	5	50	1	1	—	60	0.33
15: Zn-Cd	5	50	1	5	—	25	0.33
16: Zn-Cd	5	50	1	15	—	25	0.33
17: Zn-Cd	5	50	1	10	—	25	0.166
17: Zn-Cd	5	50	1	10	—	10	0.33

sured as a function of *L* over the range of *L* ratios varying between 1:1 and 5:1. The throwing index (*TI*) of the tested bath was the reciprocal of the slope of a plot of *M* vs. *L*.[16]

Potentiodynamic anodic linear stripping voltammetric responses were recorded in the rectangular cell containing a platinum sheet as a working electrode, a saturated calomel reference electrode and a platinum sheet as a counter electrode. Deposition of the alloy was performed on the platinum electrode at a constant deposition potential for a constant time of 60 sec. At the end of each deposition time, stripping analysis was carried out immediately in the same solution (*in situ*) by scanning the potential to a more anodic direction at a scan rate of 5 mV/sec. All experiments were carried out at constant temperature ±10°C with the help of an air thermostat.

Results and discussion

Preliminary experiments showed that in the absence of sodium gluconate, electrodeposited Zn-Cd alloys were non-adherent, rough and exhibited dendritic growth on the top of grain deposition. Addition of 10 g/L sodium gluconate to the sulfate solutions improved deposit adhesion on steel and prevented dendrite formation. Moreover, the presence of 1.0 g/L gelatin in the bath gave smooth and bright deposits. For these reasons, the electrodeposition of Zn-Cd alloys was investigated from baths containing $ZnSO_4$, $CdSO_4$, sodium gluconate and 1.0 g/L gelatin. In the presence of sodium gluconate, Zn(II) and Cd(II) ions form soluble gluconate complex species $[ZnG]^+$ and $[CdG]^+$.[17,18] Since the concentration of gluconate ions is lower than the metal ion concentrations, there will be significant amounts of free Zn(II) and Cd(II) ions in solution. In such case, codeposition of Zn-Cd binary alloy occurs via discharge of both free and complex species.

Potentiodynamic cathodic polarization

The potentiodynamic cathodic polarization curves of cadmium, zinc and Zn-Cd alloy electrodeposited onto steel substrate from gluconate baths were recorded under identical experimental conditions and are shown in Fig. 1. Inspections of the curves of Fig. 1 reveal that pure cadmium deposition starts at about -700 mV_{SCE} with a sudden rise in current density up to a limiting current density. The presence of this limiting current density indicates that the control of the deposition process is caused by the diffusion of cadmium-reducible species to the cathode surface. On the other hand, the deposition of zinc from this bath commences at about -1.1 V_{SCE}, at which point the current density rises linearly with increasing the cathodic potential, revealing that electrodeposition of pure zinc proceeds under kinetic control. The results indicate that zinc is the less noble component. The cathodic polarization curve for Zn-Cd alloy deposition is similar to that of cadmium in exhibiting a limiting current plateau, suggesting that co-deposition is controlled by the diffusion of reducible cadmium species. Since the diffusion limiting current is the maximum current for cadmium deposition in a given solution, the excess of current over the limiting current represents the partial current for zinc deposition. Hydrogen evolution may occur simultaneously with zinc co-deposition.

Figure 2 shows the effect of $CdSO_4$ concentration on the cathodic polarization for Zn-Cd alloy deposition. The data of Fig. 2 illustrate that the polarization curve for co-deposition decreases and the limiting current density increases with $CdSO_4$ concentration. The same trend was observed with increasing $ZnSO_4$ concentration as shown in Fig. 3. Therefore, one can expect an increase in cathodic current efficiency (CCE) of Zn-Cd alloy electrodeposition from a gluconate bath by increasing either the $CdSO_4$ or $ZnSO_4$ concentration. Figure 4 displays the influence of increasing the temperature on the cathodic polarization curve for

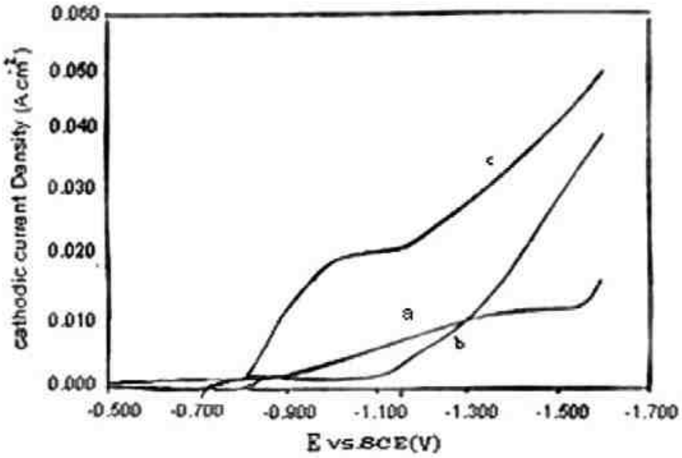

Figure 1 - Cathodic polarization curves of cadmium, zinc and Zn-Cd alloy electrodeposition onto steel substrates from plating bath numbers (Table 1): (a) 4: Cd; (b) 7: Zn; (c) 2: Zn-Cd; scan rate of 5 mV/sec and at 25°C .

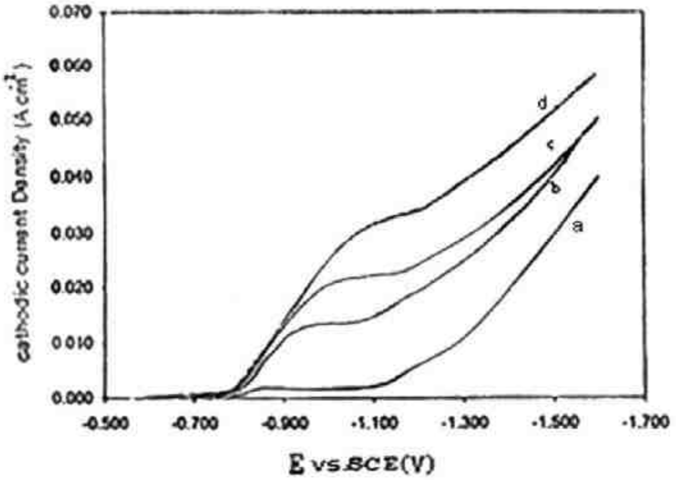

Figure 2 - *The effect of $CdSO_4$ concentration on the cathodic polarization curve of Zn-Cd alloy from baths containing 50 g/L $ZnSO_4$, 10 g/L sod*ium *gluconate and 1.0 g/L gelatin*: (*a*) No $CdSO_4$, *(b) 5 g/L $CdSO_4$, (c) 8 g/L $CdSO_4$, (d) 10 g/L $CdSO_4$; scan rate of 5 mV/sec and at 25°C.*

Zn-Cadmium alloy deposition. It is obvious increasing the temperature increases the limiting current density and decreases the cathodic polarization for the alloy deposition. Such behavior may be ascribed to the depolarization effect of temperature on activation polarization of different reducible species and to the increase in the rate of diffusion of these species towards the cathode surface.

Cathodic current efficiency and deposit composition

The cathodic current efficiencies (CCE) of Zn-Cd alloys deposited from gluconate baths under different operating variables are listed in Table 2. The table also includes the percentage of each metal in the bath and in the deposited alloy. These results show that the CCE for alloy deposition is high but less than 100% due to simultaneous evolution of hydrogen. A decrease in $ZnSO_4$ concentration in the bath decreases the CCE of alloy deposition and enhances hydrogen evolution. Nevertheless, it is clear that in all cases, the percentage of cadmium (the more noble component) in the alloy is larger than that in the bath, indicating that cadmium is preferentially deposited at the expense of zinc. These results suggest that the electrodeposition of Zn-Cd alloy from a gluconate bath is normal, as opposed to anomalous.[14] The percentage of cadmium in the deposit increases with increasing percentage in the bath and with increasing temperature. In most cases, it is found that the percentage of zinc in the deposited alloy is higher than cadmium except at the low concentration of sodium gluconate (5 g/L). The percentage of zinc is nearly equal to that of cadmium and the deposits show some dendritic growth, indicating that higher percentages of cadmium in the alloy promote the formation of dendrites.

Table 2

Cathodic current efficiencies (CCE) of Zn-Cd binary alloys deposited from a gluconate bath

Bath No.	Deposit metal content (wt%)		Bath metal content (wt%)		F%	
	Zn	Cd	Zn	Cd	Zn-Cd	H_2
2: Zn-Cd	64.5	35.5	93.9	6.1	99.48	0.52
17: Zn-Cd	72.7	27.3	93.9	6.1	95.9	4.1
3: Zn-Cd	60.0	40.0	88.46	11.54	88.6	11.4
14: Zn-Cd	49.1	50.9	93.9	6.1	94.9	5.1
1: Zn-Cd	65.5	34.5	93.9	6.1	93.3	6.7

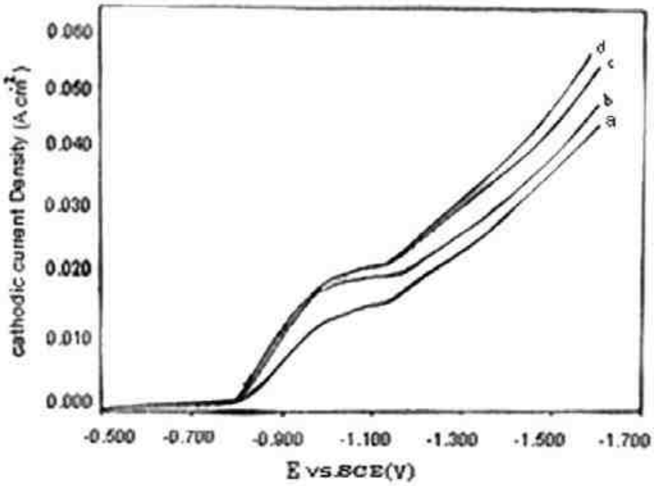

Figure 3 - *The effect of $ZnSO_4$ concentration on potentiodynamic cathodic polarization curves of Zn-Cd alloys from baths containing 5 g/L $CdSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin: (a)* No $CdSO_4$, *(b) 25 g/L $ZnSO_4$, (c) 50 g/L $ZnSO_4$, (d) 75 g/L $ZnSO_4$, (e) 100 g/L $ZnSO_4$; scan rate of 5 mV/sec and at 25°C.*

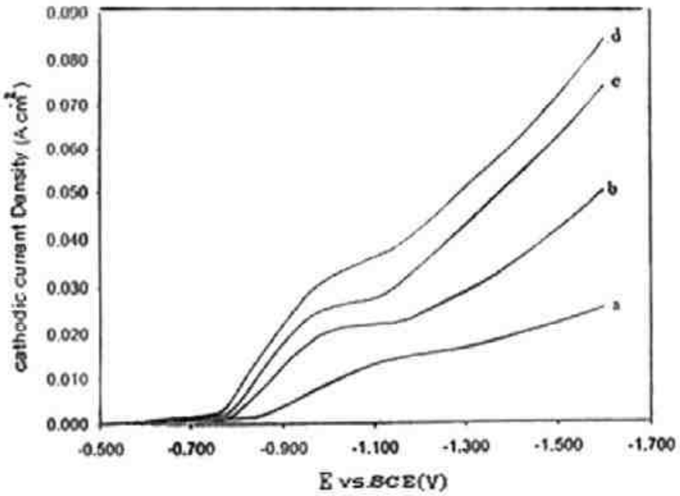

Figure 4 - *The effect of bath temperature on potentiodynamic cathodic polarization curves of Zn-Cd alloys from baths containing 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin: (a) 12°C, (b) 25°C, (c) 45°C, (d) 65°C at* a *scan rate of 5 mV/sec.*

Anodic linear stripping voltammetry (ALSV)

A series of anodic linear stripping voltammetry responses were recorded for Zn-Cd binary alloys potentiostatically electrodeposited onto a platinum electrode from the gluconate bath for a given time. At the end of the deposition, the potential of the electrodeposited electrode was swept in the positive direction at a scan rate of 5 mV/sec. The anodic stripping responses for pure cadmium, pure zinc and Zn-Cd alloy were recorded under identical experimental conditions as shown in Fig. 5. It is obvious that the ALSV responses for pure zinc and pure cadmium exhibit one stripping peak. The stripping peak of electrodeposited pure zinc is sharper and appears at a more negative potential than that for electrodeposited pure cadmium. The ALSV of the Zn-Cd electrodeposited alloy involves two stripping peaks (A_1 and A_2). The more negative stripping peak A_1 is sharp while the second peak A_2 is broad. The first peak A_1 corresponds to zinc dissolution while the second peak A_2 is due to the dissolution of cadmium.[8] The two peaks are not well separated, indicating that zinc does not dissolve completely before the cadmium dissolution potential is reached. Therefore, one can conclude that some amount of zinc mixed with cadmium in the solid phase dissolves together with cadmium within peak A_2. These data agree well with the data reported by Jović, *et al.*[8] for eutectic binary Zn-Cd alloys. On the other hand, Fedot'ev, *et al.*[7] suggested that some supersaturated solid solution of zinc in cadmium is formed. Consequently peak A_2 represents simultaneous dissolution of zinc and cadmium through the cadmium dissolution peak A_2.

Figure 6 shows the effect of the deposition potential of the Zn-Cd alloy on the ALSV curves. The data show that co-deposition of zinc only commences at a deposition potential more negative than -0.8 V_{SCE}. Further increasing the deposition potential of the Zn-Cd alloy causes a progressive increase in the charges under the two peaks. The curves of Fig. 7 show that the heights of the two anodic stripping peaks increase with increasing $CdSO_4$ content in the plating bath. Figure 8 shows the effect of sodium gluconate concentration in the bath on the anodic stripping response. The results show that an increase in gluconate content in the bath enhances the height of the zinc peak A_1 but decreases the height of cadmium peak A_2. This means that the increase in gluconate increases the percentage of zinc but decreases the percentage of cadmium in the deposited alloy. The influence of temperature on the ALSV is shown in Fig. 9. It can be seen that the height of the zinc peak A_1 increases while the height of the cadmium peak A_2 decreases with rising bath temperature. This result agrees well with the data of Table 2, taking into consideration that the electrode material upon which the alloy was deposited can affect the quantitative analysis of the deposited alloy.[7]

Throwing power and throwing index of the baths

The throwing power of gluconate baths (*TP*) calculated by Field's empirical formula at a linear ratio 5:1 under different plating variables are given in Tables 3 - 5. It is clear that the throwing power of these solutions is generally low and depend on the plating conditions. The higher the value of the *TP*, the better the throwing power of the baths. Increasing the $CdSO_4$ concentration in the bath increases the *TP*, although it decreases the cathodic polarization curves, as seen in Fig. 10 (a-c). Increasing the current density improves the throwing power. Jelink and David[16] reported that some of ambiguities associated with the use of the concept of throwing power can be resolved by the use of the throwing index (*TI*), which is obtained by plotting the metal distribution ratio, *M*,

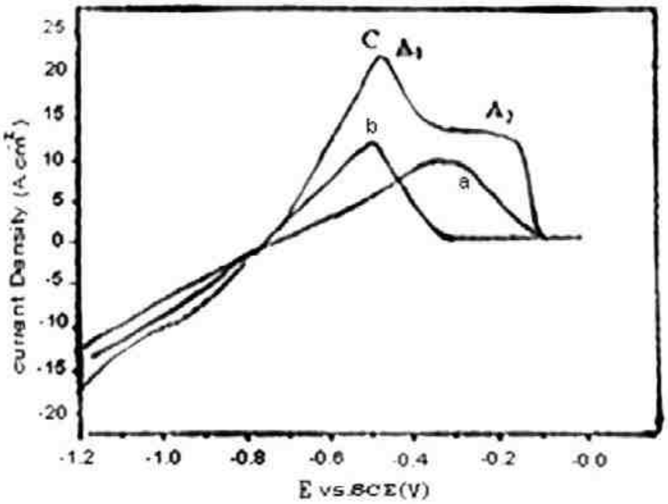

Figure 5 - *Anodic linear stripping voltammetry (ALSV) curves of pure cadmium, pure zinc and cadmium-zinc alloy electrodeposited from plating baths containing: (a) 5 g/L $CdSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin; (b) 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin; (c) 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin at a scan rate of 5 mV/sec, time = 60 sec, deposition potential = -1.1 V_{SCE} and at 25°C.*

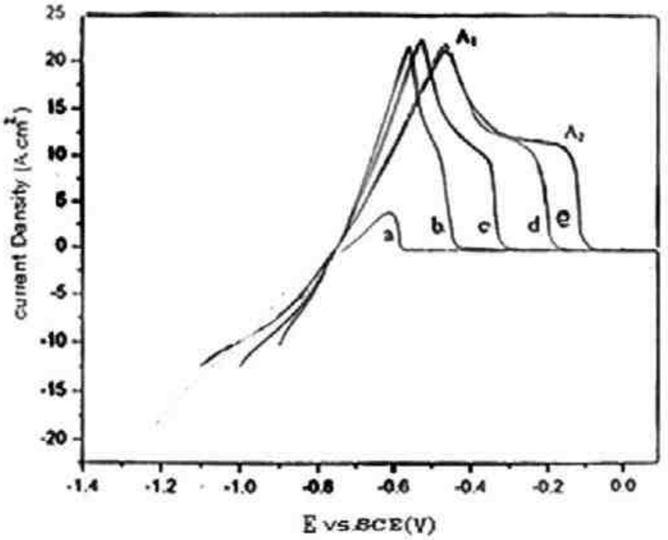

Figure 6 - *Anodic linear stripping voltammetry (ALSV) curves for Zn-Cd alloys electrodeposited from plating baths containing 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin at different deposition potentials: (a) -0.8 V_{SCE}, (b) -0.9 V_{SCE}, (c) -1.00 V_{SCE}, (d) -1.1 V_{SCE} (e) -1.2 V_{SCE}, at a scan rate of 5 mV/sec, time = 60 sec and at 25°C.*

versus the linear current distribution ratio *L* on arithmetic coordinates. As shown in Figs. 10 (a-c), the reciprocal of the slope of the line obtained is *TI* and represents a direct estimate for the bath throwing power. The values of *TI* are also listed in Tables 3 - 5. It is clear that the values of *TI* change in parallel to those calculated for *TP*.

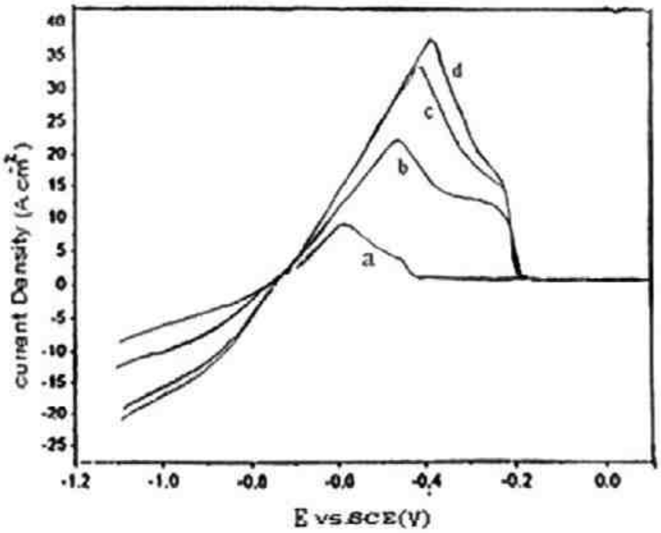

Figure 7 - *Anodic linear stripping voltammetry (ALSV) curves for Zn-Cd alloys electrodeposited at different $CdSO_4$ concentrations from plating baths containing (a) 2 g/L $CdSO_4$, (b) 5 g/L $CdSO_4$, (c) 8 g/L $CdSO_4$, (d) 10 g/L $CdSO_4$ at a scan rate of 5 mV/sec, time = 60 sec, deposition potential = -1.1 V_{SCE} and at 25°C.*

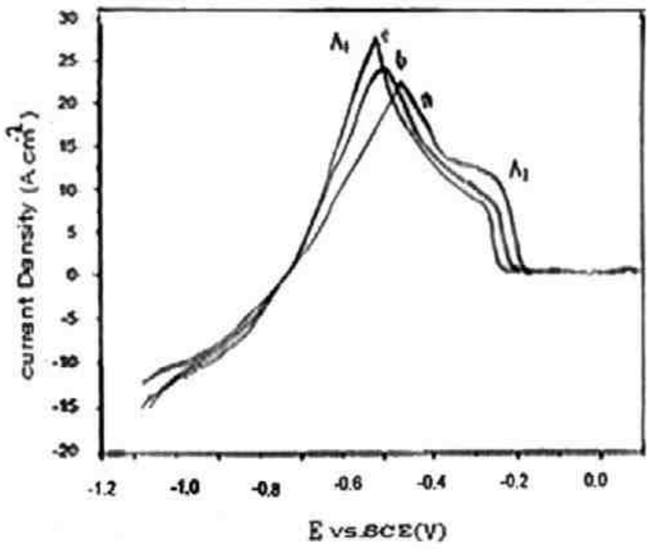

Figure 8 - *Anodic linear stripping voltammetry (ALSV) curves for Zn-Cd alloys electrodeposited at different sodium gluconate concentrations from plating baths containing (a) 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 5 g/L sodium gluconate and 1.0 g/L gelatin, (b) 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin, (c) 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 15 g/L sodium gluconate and 1.0 g/L gelatin, at a scan rate of 5 mV/sec, time = 60 sec, deposition potential = -1.1 V_{SCE} and at 25°C.*

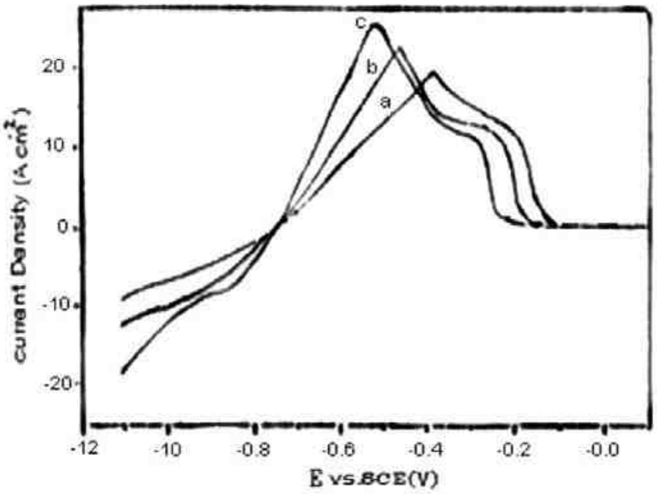

Figure 9 - *Anodic linear stripping voltammetry (ALSV) curves for Zn-Cd alloys electrodeposited from baths containing 5 g/L $CdSO_4$, 50 g/L $ZnSO_4$, 10 g/L sodium gluconate and 1.0 g/L gelatin at different bath temperatures: (a) 10°C, (b) 25°C, (c) 60°C, at a scan rate of 5 mV/sec, time = 60 sec and deposition potential = -1.1 V_{SCE}.*

Table 3

Effect of concentration of $ZnSO_4$ on throwing power and throwing index (I = 0.33 A/dm^2, T = 25°C, time = 10 min)

Bath No.	TP (%)	TI (%)
2: Zn-Cd	-10.0	0.819
6: Zn-Cd	11.11	5.0

Table 4

Effect of concentration of $CdSO_4$ on throwing power and throwing index (I = 0.33 A/dm^2, T = 25°C, time = 10 min)

Bath No.	TP (%)	TI (%)
2: Zn-Cd	-10.0	0.819
10: Zn-Cd	17.6	3.3

Table 5

Effect of current density on throwing power and throwing index (I = 0.33 A/dm^2, T = 25°C, time = 10 min)

Current Density (A/dm^2)	TP (%)	TI (%)
0.33	-10.0	0.819
0.66	33.33	2.0

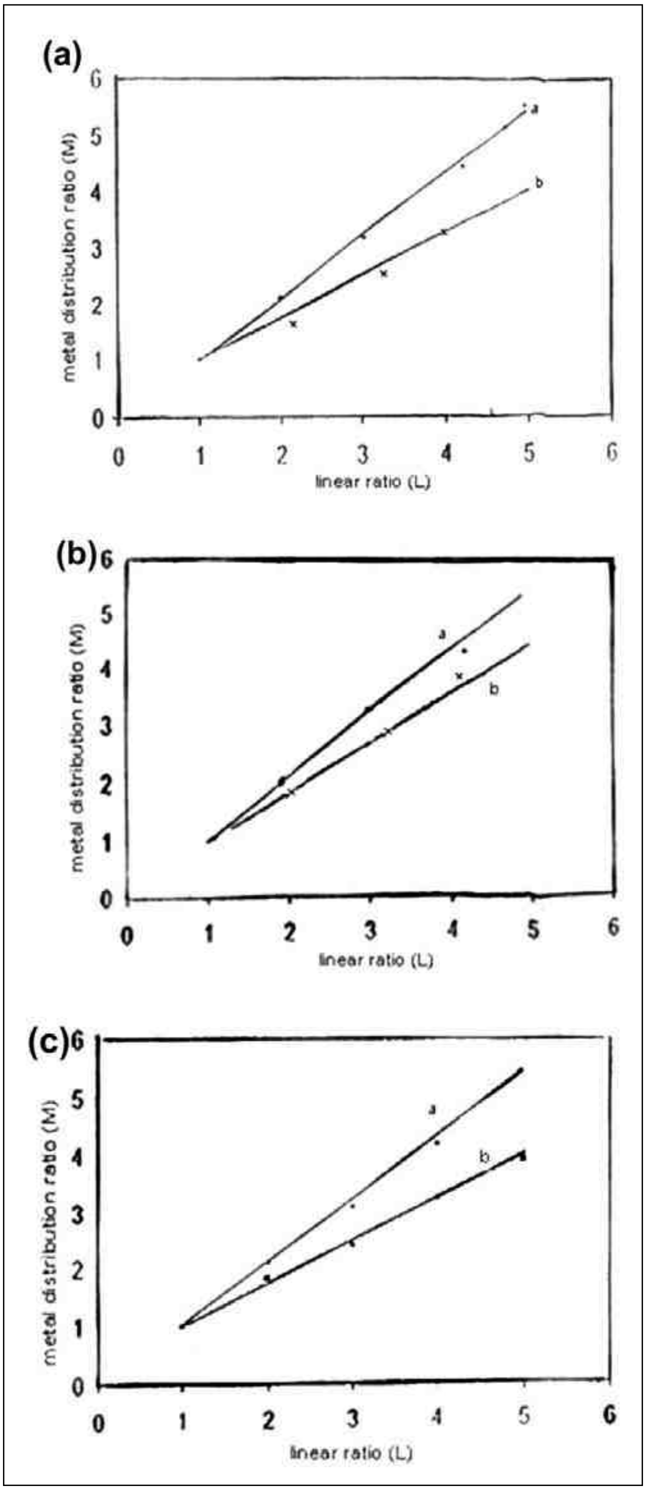

Figure 10 - *(a) The effect of current density on* the *throwing index* (TI) *obtained from plating baths containing 5 g/L* $CdSO_4$, *50 g/L* $ZnSO_4$, *10 g/L so*dium *gluconate and 1*.0 *g/L gelatin at (a) I = 0.33 A/dm*^{2}*; (b) I = 0.66 A/dm*^{2}*, at 25°C , time = 10 min.*
(b) The effect of $ZnSO_4$ *concentration on the throwing index (TI) obtained from plating baths containing (a) 5 g/L* $CdSO_4$, *50 g/L* $ZnSO_4$, *10 g/L so*dium *gluconate and 1*.0 *g/L gelatin (b) 5 g/L* $CdSO_4$, *100 g/L* $ZnSO_4$, *10 g/L so*dium *gluconate and 1.0 g/L gelatin, at 25°C, time = 10 min and I = 0.33 A/dm*^{2}.
(c) The effect of $CdSO_4$ *concentration on the throwing index (TI) obtained from plating baths containing (a) 5 g/L* $CdSO_4$, *50 g/L* $ZnSO_4$, *10 g/L so*dium *gluconate and 1*.0 *g/L gelatin,* (b) *10 g/L* $CdSO_4$, *50 g/L* $ZnSO_4$, *10 g/L so*dium *gluconate and 1*.0 *g/L gelatin, at 25°C, time = 10 min and I = 0.33 A/dm*^{2}.

Conclusions

Electrodeposition of Zn-Cd binary alloys from gluconate baths was studied as a function of bath composition, temperature and current density on mild steel substrates. Adherent, smooth and bright deposits were obtained in the presence of 10 g/L sodium gluconate and 1.0 g/L gelatin at pH~4.5, 25°C and 0.33 A/dm^2. The result showed that in all cases preferential deposition of cadmium, the more noble component, occurs. Therefore, the co-deposition process could be classified as is normal, as opposed to anomalous. Deposition of cadmium in the alloy takes place under diffusion control. The cathodic current efficiency is generally higher and close to 100%. The throwing power of the bath is poor. Anodic linear stripping voltammetry ALSV involved two peaks, the first representing dissolution of zinc while the second (the more positive) reflecting dissolution of cadmium.

References

1. D. Crotty, *Metal Finishing*, **94** (9), 54 (1996).
2. G. Roventi, *et al.*, *J. Appl. Electrochem.*, **30** (2), 173 (2000).
3. H. Kim, B.N. Popov & K.S. Chen, *J. Electrochem. Soc.*, **150** (2), C81 (2003).
4. I. Kirilova, I. Ivanov & St. Rashkov, *J. Appl. Electrochem.*, **27** (12), 1380 (1997).
5. M.M. Abou-Krisha, A.M. Zaky & A.A. Toghan, *Asian J. Biochem.*, **1** (1), 84 (2006).
6. M.M. Abou-Krisha, *J. Appl. Surf. Sci.*, **252** (4), 1035 (2005).
7. N.P. Fedot'ev & P.M. Vyacheslavov, *Plating*, **57** (7), 700 (1970).
8. V.D. Jović & V. Jevtić, *J .Serb. Chem. Soc.*, **61**, 479 (1996).
9. Y. Fujiwara & H. Enomoto, *Surf. & Coat. Technol.*, **35** (1-2), 101 (1988).
10. J.F. Colin & C.P.F. Young, *Proc. 1967 General Meeting*, New Orleans, LA (March, 1995).
11. V.D. Jović, *et al.*, *Mater. Sci. Technol.*, **7** (11), 1021 (1991).
12. V.D. Jović, *et al.*, *Electrochim. Acta*, **34** (8), 1093 (1989).
13. K.H. Wong & P.C. Andricacos, *J. Electrochem. Soc.*, **137** (4), 1087 (1990).
14. A. Brenner, *Electrodeposition of Alloys - Volumes 1 & 2*, Academic Press, New York, NY, 1963.
15. S. Field, *Metal. Ind.* (London), **44**, 416 (1934).
16. R.V. Jelinek & H.F. David, *J. Electrochem. Soc.*, **104** (5), 279 (1957).
17. G N. Escandar, *et al.*, *Polyhedron*, **13** (6-7), 909 (1994).
18. E. Raub & K. Muller, *Fundamentals of Metal Deposition*, Elsevier Publishing Co., Amsterdam and New York (1967).

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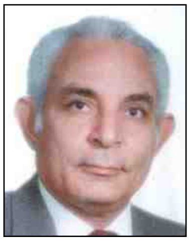

Abd El Rehim

Prof. Dr. Emad A. Abd El Meguid *is the Head of Inorganic Chemistry and Mineral Resources Division at the National Research Centre (NRC), Dokki, Cairo, Egypt. His scientific research interests are in the domain of electrochemistry of solid-liquid interfaces which include studies of the initial stages of metal deposition on single crystal surfaces and nano-structuring of metallic surfaces, well ordered of bimetallic, nano-particle electrocatalysts, electroless plating and electroplating of metals and alloys, as well as corrosion and corrosion protection of metallic materials. Prof. Abd El Meguid's research activities are aimed to meet the requirement of many advanced technologies such as nano-devices, nanosensors, nanomaterials for electrochemical energy conversion, corrosion and corrosion control.*

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Test Your Plating I.Q. #464

By Dr. James H. Lindsay

Alloy plating

1. What is anomalous codeposition?

2. What term is used to describe the opposite of anomalous codeposition?

3. Compared to pure zinc, a zinc-nickel alloy has a corrosion potential closer to that of the underlying steel. How does this affect the corrosion behavior?

4. The same metallurgical phases occur in electrodeposited alloys as in metal-formed alloys (i.e., as in metallurgical phase diagrams. **True** or **false**.

5. Which of the following tend to increase the amount of the more noble element (i.e., less active) in the alloy deposit?
   a) Current density
   b) Agitation
   c) Temperature
   d) All of the above
   e) None of the above

Answers on page 64.

Q&A