Available online at www.elixirpublishers.com (Elixir International Journal)

Organic Chemistry

Elixir Organic Chemistry 171 (2022) 56517-56522

ISSN: 2229-712X

Effects of Current Density and Deposition Time on Corrosion Resistance of Electrodeposited Zn-Ni-SiO_2 Coating

Nguyen Thi Thanh Huong[1], Le Ba Thang[1], Truong Minh Hieu[1], Le Duc Bao[1] and Pham Thi Thu Giang[2]

[1]Institute for Tropical Technology, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Cau Giay, Hanoi, Viet Nam; [2]Hanoi University of Industry, 298 Minh Khai, Bac Tu Liem, Hanoi, Vietnam.

ARTICLE INFO

Article history:

Received: 5 March 2021;

Received in revised form:

8 October 2022;

Accepted: 18 October 2022;

Keywords

Alloy Coating,

Composite Electrodeposition,

Corrosion Resistance,

SiO_2nanoparticle.

ABSTRACT

This work aims to evaluate the effects of current density and plating time on the corrosion resistance of $ZnNiSiO_2$ electroplated coating. For the plating time, the results showed that coating thickness increased with increasing the plating time. The average thickness was 6, 15 and 25 µm, when used plating time of 10, 30 and 50 minutes, respectively.Whereas, when the current density values varied from 1 A/dm^2 to 5 A/dm^2, the coating thickness was in range of 14.7 - 15.3 µm, with the same plating times. After 900 hours of exposure to salt spray, the surface appearance of coatings indicated that the plating time of 30 minutes provided the highest corrosion resistance. These data were coherent with the findings from polarization curve measurement.

1. Introduction

To protect the ferrous metals against corrosion, zinc alloy coatings exhibited higher corrosion resistance than pure zinc coating, while maintaining their sacrificial protection effect [4-6]. It was reported in literature that zinc-nickel coatings providedhigher corrosion protection for steel than the neat zinc and cadmium coatings [1-6]. Among the zinc alloy coatings, zinc-nickel alloy coating has attracted significant attention from both research and industry due to their high corrosion resistance [7-9] and good mechanical properties [10]. In fact, for industrial application, the improvement of both mechanical and anticorrosion properties for zinc-nickel alloy coatings necessary and required [2, 11, 12]. In case of zinc-nickel electroplated coatings, their properties mostly depended on both plating baths (composition/pH) and plating parameters (temperature, current density, plating potential) [13-15]. To evaluate the corrosion resistance of zinc-nickel alloy coating in aggressive environment, salt spray test has been considered as a typical method [17]. From the exposure to salt spray test, authors in [16] reported that there were various factors affecting the anticorrosion property of zinc-nickel alloy coating [16]. In this paper, the effects of current density and plating time on the corrosion resistance of $ZnNiSiO_2$ electroplated coating have been evaluated systematically.

2. Experiments

Mild steel (SPHC - JIS G3131) substrates were low carbon steel with the chemical composition: C(≤0.15%), Mn (≤0.6%), P (≤0.05%), S (≤0.05). The size of steel speciments was 100×50×1.2 mm. Before plating, the steel coupons was polished using silicon carbide (SiC) papers down to a grid size of #280 from #600, then degreased andpickled.The steel coupons werethen activated with 5% HCl(aq) for 5seconds.

The nanosilica powder (AEROSIL 200, Belgium) with average particle size of 15 nm and surface area of 200 m^2/g was used as received without anyfurther treatment or modification. Before electrodeposition, the silica nanoparticles with concentration of 5 g/L were dispersed in the electrolytic bath by ultrasonic at 20 kHz for 30 min. These silica nanoparticles were maintained in an electrolytic bath in suspension by continuous magnetic stirring of 200 rpm for at least 24 hours before deposition.The composition of electrolytic bath (20 litres in volume) was 60 g/L $ZnCl_2$, 250 g/L NH_4Cl, 150 g/L $NiCl_2$; 20 g/L H_3BO_3, and 5g/L nanosilica at pH 5.6. The plating parameters were 1-5 A/dm^2 current density, 10-20 minutes plating time at plating temperature of 30^{o}C.

After plating, the average thickness of the alloy coating was measured using MiniTest 600 (ElektroPhysik, Germany). The plated samples were kept in a decicator at room temperature before surface analysis and corrosion tests. The surface morphology and chemical composition of plated samples were investigated by Scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDX) – (SEM/EDX, JEOL -6510, Japan).

The corrosion behavior of the $ZnNiSiO_2$ coating in 3.5% NaCl solution was evaluated by polarization test (scan rate of 2 mV/s) using Bio-Logic VSP-300 potentiostat. For polarization test, a conventional three-electrode cell was used with the plated sample as working electrode, along with the Saturated Calomel Electrode (SCE) as reference electrode and the platinum mesh as auxiliary electrode.

The salt spray test for $ZnNiSiO_2$ coatings was performed in the Q-FOG CCT-600 chamber according to the standard JIS H8502 (using 5%NaCl solution at 35˚C). The surface appearance (white/red rust corrosion products) of plated samples before and after exposure to salt spray was recorded and photographed.

3. Results and Discussion

3.1 Coating Characterization

Tables 1 and 2 present the values of average thicknessof $ZnNiSiO_2$ coatings with various plating current densities and plating times, respectively. As can be seen in table 1, the thickness of $ZnNiSiO_2$ coatings slightly increased with increasing current density from 1 to 5 A/dm^2. Thus, the current density had only minor influence to the coating thickness. However, by increasing the plating time (Table 2), the thickness of $ZnNiSiO_2$ coatings steadily increased. After 50 minutes of plating, the coating thickness reached a value of 25 µm. For the comparative study on thickness mearurement, Axiovert40MATdevice was used for the $ZnNiSiO_2$ coating with plating time of 20 minutes and plating current density of $3A/dm^2$ (Figure 1). As shown in figure 1, the values of coating thickness were quite similar at all positions with average value of 13.53± 0.66 µm. Thus, both methods of thickness mearurement were good coherent.

Figure 2a presents the SEM image of $ZnNiSiO_2$ coating with plating time of 30 minutes and plating current density of $2A/dm^2$. Figure 2b presents the SEM image of $ZnNiSiO_2$ coating with plating time of 20 minutes and plating current density of $3A/dm^2$. As seen in Figure 2, the composite coating exhibited the pyramid-shaped crystal structure. EDX analysis (Figure 3 and Table 3) indicated the high content of SiO_2 in the coating (2.18 wt.%), with the Zn : Ni weight ratio of Zn (65.5 wt.%) : Ni (14.1 wt.%). High content of SiO_2 in the $ZnNiSiO_2$ coating confirmed the successful inclusion plating.

3.2. Electrochemical test

Figures 4 and 5 present the potentiodynamic polarization curves of $ZnNiSiO_2$ coatings plated with different current densities and plating times, respectively. From the measured curves, corrosion current density and corrosion potential of the coatingswere deducted using Tafel extrapolation and summarized in Tables 4 and 5 respectively.

Regarding the corrosion potential E_{corr}, from these data the effects of Ni content in $ZnNiSiO_2$ coating on its corrosion potential could be evaluated roughly. In general, increasing the Ni content in $ZnNiSiO_2$ coating shoud lead to an increase in its corrosion potential. In other word, the shift of corrosion potentialmight indicate a change of composition ratio in the alloy coating.

In case of corrosion current density i_{corr}, as shown in Table 4, the plating parameters of 30 minutes plating time and 2 A/dm^2 current density provided the lowest corrosion current density (9.22×10^{-6} A/cm^2). When increased the plating current density to 3 and 5 A/dm^2, the corrosion current density of coatings increased upto 35.12×10^{-6} and 25.95×10^{-6} A/cm^2, respectively. However, when increased the plating time to 40 and 50minutes (Table 5), the corrosion current density of coatings decreased down to 6.75×10^{-6} and 5.75×10^{-6} A/cm^2, respectively.

Regarding the effect of coating thickness to the corrosion current (corrosion rate), the highest value of corrosion current density (39.40×10^{-6} A/cm^2) was observed in $ZnNiSiO_2$ coating plated at current density of $2A/dm^2$ during 10 minutes, This coating had the smallest thickness (6 µm) among these as-plated coatings (Tables 1 and 2). When increased the plating time, the coating thickness increased, leading to a decrease in, corrosion rate. In case of plating times were 10; 20; 30; 40 and 50 minutes, the corrosion rates of as-plated coatings were 0.732; 0.264; 0.173; 0.125 and 0.106 mm/year, respectively.

3.3. Salt spray test

In addition to the electrochemical test, the corrosion resistance of $ZnNiSiO_2$ coatings was evaluated by salt sparay test. Figure 6 shows the photos of surface apperence after 900 hours-salt spray test of $ZnNiSiO_2$ coatings plated at different plating current densities. Table 6 presents the time when first red rust spot was seen on the surface of these coatings. As seen in Table 6, the longest time (900 hours) for appearing the first red rust spot was observed on the surface of coatings plated at current density of $2A/dm^2$. This is the reason why $2A/dm^2$ current density was fixed/selected when studied the effects of plating time.

Figure 7 presents the photos of surface apperence after 900 hours-salt spray test of $ZnNiSiO_2$ coatings plated at different plating time. Table 7 shows the time when first red rust spot was seen on the surface of these coatings. As shown in Table 7, after 200 hours the coating plated in 10 minutes started appearing the first red rust spots on its surface, whereas it was 800 hours for the coating plated in 20 minutes. This result confirmed that the longer plating time (thicker coating) provided the better corrosion protection for steel subtrates. The coatings with longer plating times, such as 40 and 50 minutes, began to appear the first red spots after 850 and 890 hours of salt spray test, respectively. Thus, the highest corrosion resistance was achieved by the optimal plating parameters of 30 minutes plating time and $2A/dm^2$ current density. These findings are cohenrent with the results from polarization curve measurement.

4. Conclusions

The main findings of this study were:

1. Thickness of $ZnNiSiO_2$ coatings slightly increased with increasing current density from 1 to 5 A/dm^2. Thus, the current density had only minor influence to the coating thickness. By increasing the plating time, the thickness of $ZnNiSiO_2$ coatings steadily increased. After 50 minutes of plating, the coating thickness reached a value of 25 µm.
2. Potentiodynamic polarization indicated that the plating parameters of 30 minutes plating time and 2 A/dm^2 current density provided the lowest corrosion current density (9.22×10^{-6} A/cm^2).
3. Salt spay test indicated that plating time of 20 minutes provided the highest corrosion resistance. The first red spot only began to appear on the surface of coating 900 hours of exposure to salt fog.

Acknowledgment

This study was financial supported by the VietnamAcademy of Science and Technology (project code: VAST03.02/19-20)

Table 1. Average thickness of $ZnNiSiO_2$coatingsby different plating current densities, (measured by MINITEST600, plating time = 20 minutes)

Current density (A/dm^2)	1	2	3	4	5
Average thickness of coating (µm)	14.7	15	14.9	15.1	15.3

Table 2. Average thickness of the $ZnNiSiO_2$coatings with different plating times (measured by MINITEST600, current density = $2A/dm^2$)

Plating time (min)	10	20	30	40	50

Average thickness of coating (µm)	6	10	15	19	25

Table 3. Chemical composition of $ZnNiSiO_2$ coating (plated during 20 minutes at current density of 3A/dm^2).

Spectra	Si	Fe	Ni	Zn	Total
001	1,92	16,16	14,24	67,69	100
002	2,14	20,26	15,1	62,5	100
003	2,48	18,23	12,96	66,32	100
Average of 3 spectra	2,18	18,21	14,1	65,5	100

Table 4. Values of E_{corr} and i_{corr} for the $ZnNiSiO_2$ coatings with different plating current densities(plating time = 30 minutes)

Plating current density (A/dm^2)	E_{corr} (mV vs SCE)	i_{corr} (A/cm^2)
1	-733	14.77×10^{-6}
2	-783	9.22×10^{-6}
3	-697	35.12×10^{-6}
4	-749	26.04×10^{-6}
5	-713	25.95×10^{-6}

Table 5. Values of E_{corr} and i_{corr} for the $ZnNiSiO_2$ coatings with different plating times (current density = 2A/dm^2)

Plating time (min)	E_{corr} (mV vs SCE)	i_{corr} (A/cm^2)
10	-531	39.40×10^{-6}
20	-570	14.24×10^{-6}
30	-602	9.35×10^{-6}
40	-662	6.75×10^{-6}
50	-669	5.75×10^{-6}

Table 6. Time for appearing the first red rust spot on the surface of $ZnNiSiO_2$ coatings, prepared at different plating current densities (plated during 30 minute)

Plating current density (A/dm^2)	Time for appearing the first red spot (hour)
1	670
2	900
3	850
4	700
5	650

Table 7. Time for appearing the first red rust spot on the surface of $ZnNiSiO_2$ coatings, prepared at different plating times (current density = 2A/dm^2)

Plating time (min)	Time for appearing the first red spot (hour)
10	200
20	800
30	900
40	850
50	890

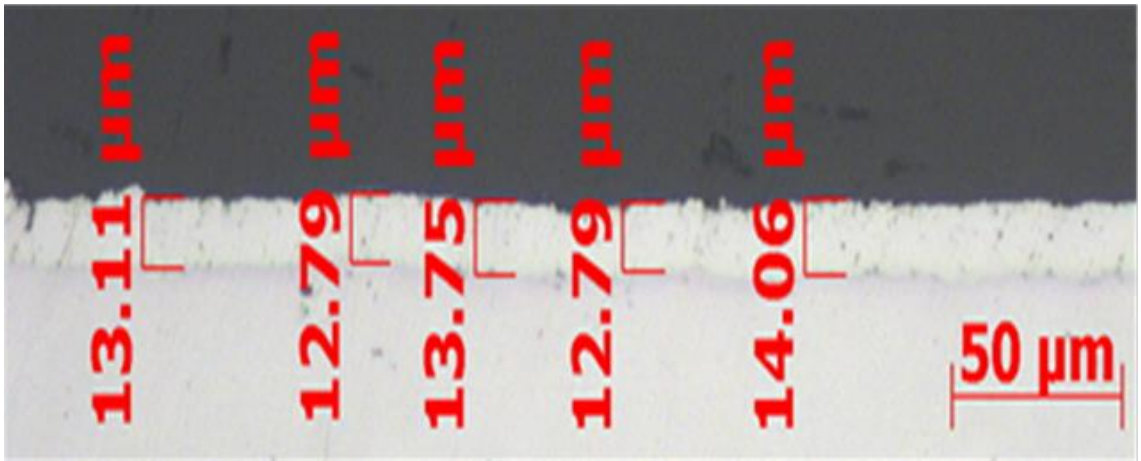

Figure 1. Thickness values of $ZnNiSiO_2$ coating, with plating time of 20 minutes and plating current density of 3A/dm^2 (measured by Axiovert40MAT)

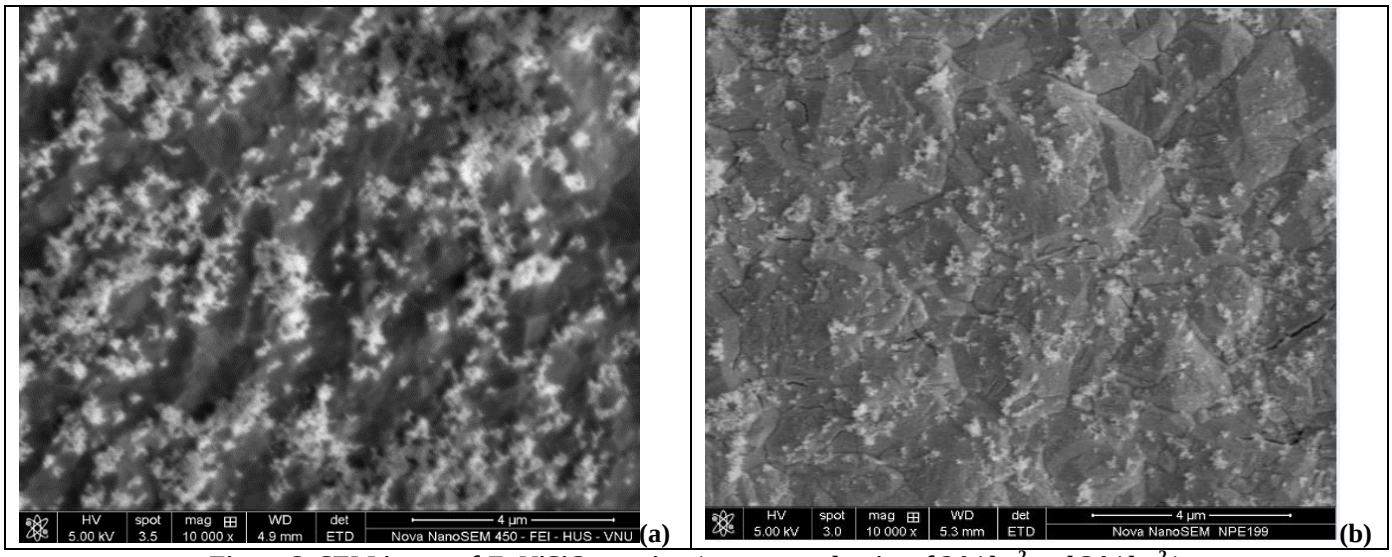

Figure 2. SEM image of $ZnNiSiO_2$ coating (at current density of $2A/dm^2$ and $3A/dm^2$)

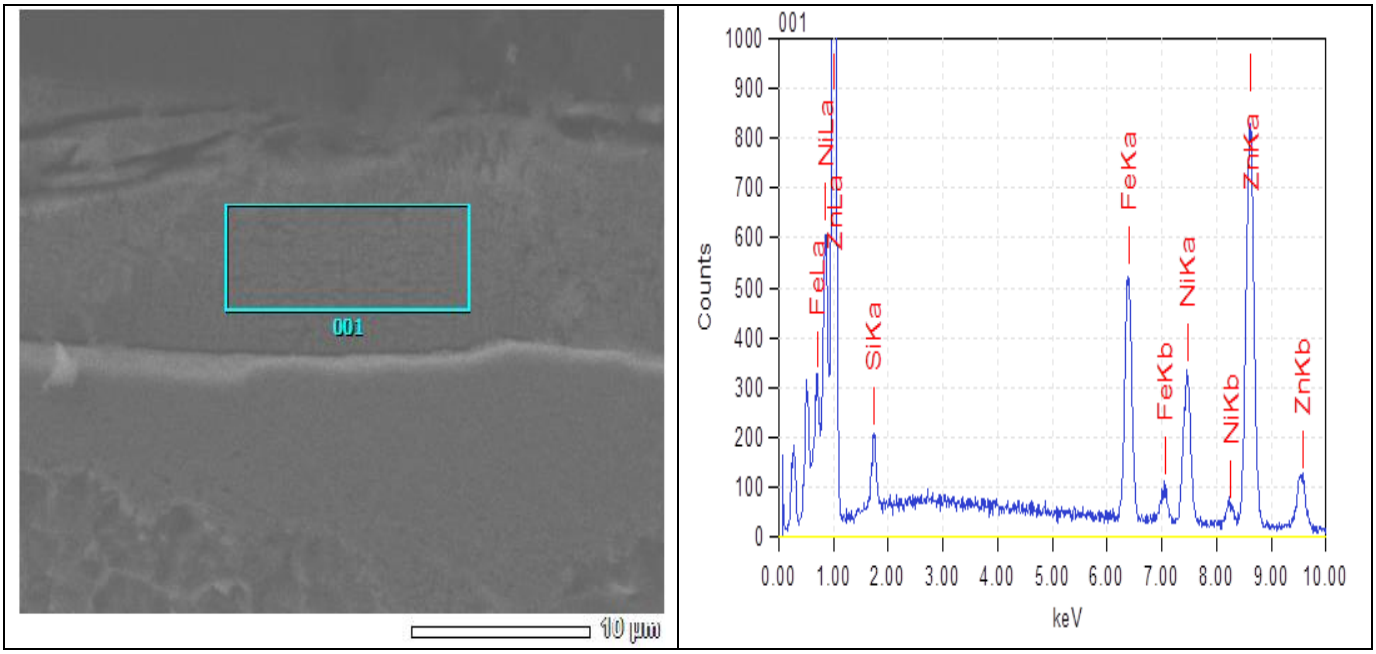

Figure 3. EDX spectrum of the $ZnNiSiO_2$ coating (plated during 20 minutes at current density of $3A/dm^2$).

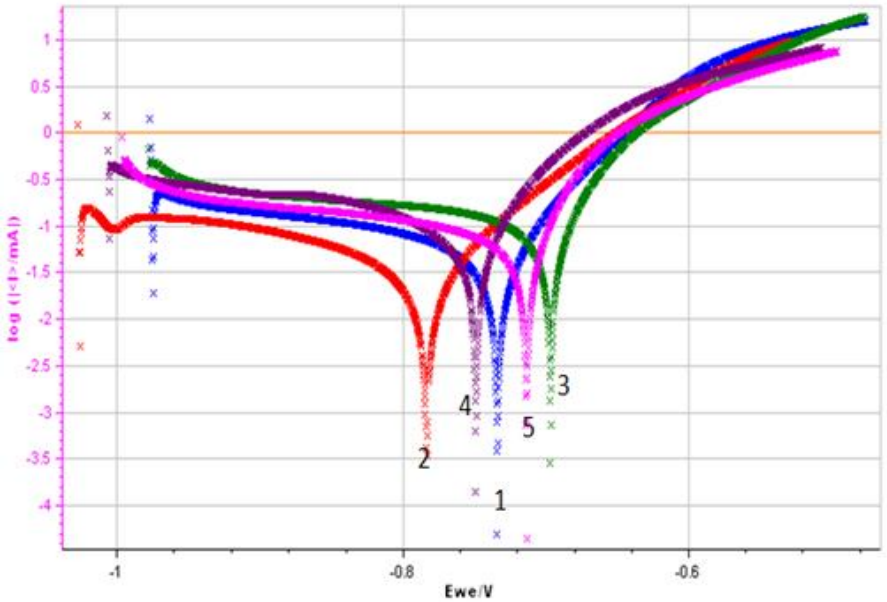

Figure 4. Polarization curves of $ZnNiSiO_2$coatings with different plating current densities (plating time = 30 minutes): (1) 1 A/dm^2, (2) 2 A/dm^2, (3) 3 A/dm^2, (4) 4 A/dm^2 and (5) 5 A/dm^2.

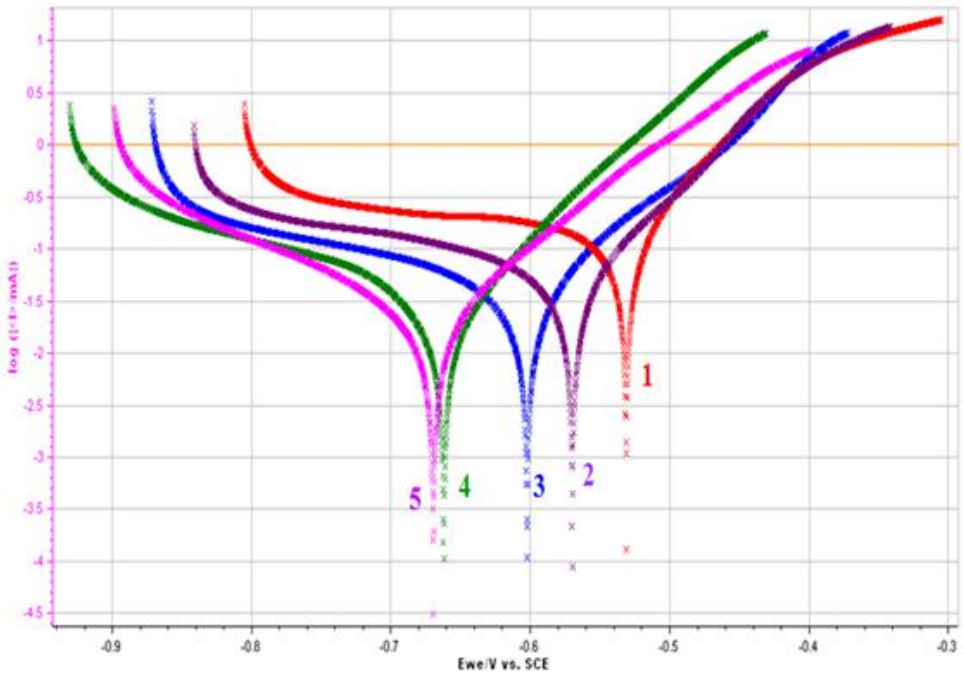

Figure 5. Polarization curves of $ZnNiSiO_2$coatings with different plating times (current density = 2A/dm^2):(1) 10 min, (2) 20 min, (3) 30 min, (4) 40 min and (5) 50 min.

1 A/dm^2 2 A/dm^2 3 A/dm^2 4 A/dm^2 5 A/dm^2

Figure 6. Photos of surface apperence for $ZnNiSiO_2$ coatings plated at different plating current densities (after 900 hours salt spray test)

10 min 20 min 30 min 40 min 50 min

Figure 7. Photos of surface apperence for $ZnNiSiO_2$ coatings plated at different plating time (after 900 hours salt spray test)

References

1.Hall, D.E., Plat. Surf. Finish., 1983, vol. 70, p. 59.
2.Gavrila, M., Millet, J.P., Mazille, H., et al., Surf. Coat. Technol., 2000, vol. 123, p. 164.
3.Bajat, J.B., Maksimović, M.D., and Radović, G.R., J. Serb. Chem. Soc., 2002, vol. 67, p. 625.
4.Ravindran, V. and Muralidharan, V.S., Bull. Mater. Sci., 2006, vol. 29, p. 293.
5.Fei, J.Y., Liang, G.Z., Xin, W., L., and Wang, W., J. Iron Steel Res. Int., 2006, vol. 13, p. 61.
6.Coleman, D.H. and Popov, B.N., J. Appl. Electrochem., 1998, vol. 28, p. 889.
7.Hegde, A.C., Venkatakrishna, K., and Eliaz, N., Surf. Coat. Technol., 2010, vol. 205, p. 2031.
8.Eliaz, N., Venkatakrishna, K., and Hegde, A.C., Surf. Coat. Technol., 2010, vol. 205, p. 1969.

9.Ashassi-Sorkhabi, H., Hagrah, A., Parvini-Ahmadi, N., and Manzoori, J., Surf. Coat. Technol., 2001, vol. 140, p. 278.
10.Boonyongmaneerat, Y., Saenapitak, S., and Saengkiettiyut, K., J. Alloys Compd., 2009, vol. 487, p. 479.
11.Qiao, X., Li, H., Zhao, W., and Li, D., Electrochim. Acta, 2013, vol. 89, p. 771.
12.Wykpis, K., Popczyk, M., Niedbala, J., et al., Coat., Mater. Sci., 2012, vol. 1, p. 10.
13.Pedroza, G.A.G., de Souza, C.A.C., Carlos, I.A., and de Andrade Lima L.R.P., Surf. Coat. Technol., 2012, vol. 206, p. 2927.
14.Magagnin, L., Nobili, L., and Cavallotti, P.L., J. Alloys Compd., 2014.
15.Nguyen Thi Thanh Huong, Le Ba Thang, Le Duc Bao, Truong Thi Nam and Nguyen Van Chien, Corrosion Resistance of ZnNi/Nanosilica Alloy Coating on Carbon Steel, Elixir Corrosion & Dye 134 (2019) 53588-53592.
16.Japanese industrial standard JIS H 8502:1999.
17.Nguyen Huy Dung et al., The effects of SiO2 and Al2O3 on the corrosion resistance of ZnNi alloys in natural and artificial environments, Journal of Science and Technology, volume 47, No. 5 (2009), 87-98.