

The role of inert particles incorporated in (Zn-Ni) layer on corrosion resistance of carbon steel

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Abstract:

This work represents as an attempts to use and enhance (Zn-Ni) electrodeposited coatings to replace the toxic Cd used in aerospace industries. Fortunately, it is found that this coating provide sacrificial behavior to steel substrates for long periods.

Results obtained from this work showed a great reduction in corrosion currents caused by the addition of inert nano-particles to (Zn-Ni) deposits.

These improvements were observed in all tests conducted in tap water, salt solution and acidic solution.

Keywords: electrodepositing, corrosion, protection against corrosion, nanoscale, (Zn-Ni) coating layer.

1. Introduction:

Electroplating is the application of a metal coating to a metallic or other conducting surface by an electrochemical process. The article to be plated (the work) is made the cathode (negative electrode) of an electrolysis cell through which a direct electric current is passed, [1].

The article is immersed in an aqueous solution (the bath) containing the required metal in an oxidised form, either as an aquated cation or as a complex ion. The anode is usually a bar of the metal being plated. During electrolysis metal is deposited on to the work and metal from the bar dissolves [2-4].

Electrochemical deposition is generally used for the growth of metals and conducting metal oxides because of the following advantages: (i) the thickness and morphology of the nanostructure can be precisely controlled by adjusting the electrochemical parameters, (ii) relatively uniform and compact deposits can be synthesized in template-based structures, (iii) higher deposition rates are obtained, and (iv) the equipment is inexpensive due to the non-requirements of either a high vacuum or a high reaction temperature, [5-7].

Plating baths are composed of one or several metals that are used to deposit in the electrode surface. During the plating process, the metal concentration is decreased with time. The metal concentration and properties effecting on the product quality therefore should not be too low to use for plating on the substrate material, [8,9].

The electroplating of Zn-Ni alloy has been utilized for the highly corrosion-resistive coating of steel, specially for the construction of automobiles. The electrodeposition of the Zn-Ni alloy is classified by Brenner) into Anomalous codeposition, in which the electrochemically less noble Zn is deposited preferentially under most plating conditions, [3,5,10].

2. Experimental work:

First, the part must be thoroughly cleaned, preferably by bead blasting and/or electro-stripping to remove rust. If the surface has very minor pitting (orange peel texture) then this can usually be filled using a copper plate. The chemical composition of the used sample is shown in table (1).

The samples were of disks shape with diameter 15mm and 2mm thickness.

Specimens were electroplated in the as grinding conditions. Samples were then cleaned. The components of plating solution are shown in table (2):

The plating cell is shown in Figure (1) it consists of (29*21*18) cm polyethylene basin in the form of cubic. The electrodes were Nickel as an anode while the cathode was the carbon steel samples.

To homogenize the prepared solution it was held at room temperature for (24 hours). It was stirred for (15 min.). The thickness of the deposited layer varied between (20-45) μm .

As can be seen the first sample was coated with a layer of (Zn –Ni). The average thickness was 20 μm . The second sample, however, SiC particle of nano size was incorporated in this (Zn – Ni) deposited layer.

Several tests were carried out such as X-ray fluorescence, corrosion test, surface roughness, and Porosity.

3. Results and Discussion:

3.1 XRF

Results obtained from XRF are shown in table (3).

The average thickness of the deposited layer of (Zn-Ni) was (20 μm), while it was (45 μm) for (Zn-Ni- μSiC) and (40 μm) for (Zn-Ni-nSiC).

These results indicated that the deposit rates of last two coating layers are greatly faster than for (Zn-Ni). This can be attributed to the high diffusivity of the species caused by the presence of SiC.

3.2 Corrosion Behavior

3.2.1 Carbon steel:

Corrosion behavior was evaluated by using Tafel extrapolation technique. Currents density of all tested samples are shown in figures (2-4) conducted in deferent corrosive media. However, values of corrosion currents are presented in table (4).

The corrosion current of uncoated carbon steel was (38.02, 46.60 and 7660) $\mu\text{A}/\text{cm}^2$, in tap water, 3% NaCl and 3% HCl respectively.

3.3.2 Zn-Ni coated steel:

The current density of (Zn-Ni) coating layer in the same media were (18.29, 21.60, 4050) $\mu\text{A}/\text{cm}^2$ respectively, all tested samples are shown in figures (5-7).

It is well established that Zn is an anode with respect carbon steel, while Ni is cathode. Fortunately, Zn-Ni layer acts as an anode to steel. This means Ni loosed its nobility by the addition of zinc. It changes the electrode potential. A significant decrease in corrosion current density occurred in all media. For instance, the corrosion current was only (0.481, 0.463, 0.528) respectively with respect to base metal.

3.3.3 Zn-Ni-*m*SiC coated steel:

An attempt was made to improve the corrosion resistance (Zn-Ni) coating layer by the incorporation of SiC particles micro size. A substantial decrease in corrosion current density results when *m*SiC was added. For examples it was only (0.0615, 0.303 and 0.175) respectively with respect to base metal as show in figures (8-10). These results are very low compared to those for (Zn-Ni) coated layer. This improvement may be attributed to inert SiC particles and there effects on diffusivity of the reactants.

3.3.4 Zn-Ni-*n*SiC coated steel:

For further improvement it was intended to add SiC nano-particles to the coating layer. A great redaction in corrosion current density was observed when SiC nano-particles were added. For instance it was only (0.0087, 0.226 and 0.028) respectively with respect to base metal, as show in figures (11-13). It is clear from above that SiC nano-particles are more effective than micro SiC in improving corrosion resistance.

The reasons stand behind these improvements are probably several. Firstly, SiC particles are inert and expected to be stable and act as a disruptive between the reactants. Therefore, it reduced the cross-section of the layer exposed to the corrosive medium. Porosity however, played a deferent role. It increases surface area exposed to the medium. In addition it reduced the porosity.

3.4 Topography of the coating layers.

3.4.1 Surface roughness :

It is clear from table (5) the roughness of (Zn-Ni-*m*SiC) is the highest. This may be attributed to the bigger SiC particles size. This idea is supported by the fact that (Zn-Ni) layer which is free of SiC particles possesses the lowest value of surface roughness. The surface roughness of the deposited layers are presented in table (3).

3.4.2 Porosity

Porosity however, seems to follow the same sequence, i.e porosity of (Zn-Ni) layer is once again has the lower value. As can be seen in table (6) the porosity increases when SiC particles of micro-size were added. This increase expected since it is associated with the large particles of SiC. This explanation is supported by the fact that nano-size particles significantly lower both the porosity and corrosion current density. This is due to possible filling the pores by these fine particles. When SiC particles were incorporated into (Zn-Ni), the nano-size SiC reduces the corrosion current density to the lowest value, table (6).

However when the samples were coated with (Zn-Ni) deposit, a significant reduction in current density occurred, Table5

It is found throughout this work that the optimum thickness (20 μ m) more than this thickness the deposited layer crack in this spalled. If the layer thickness is less than (20 μ m), it is no longer protective.

Spalling may be the thick layers may be attributed to the defects, internal and loss of adhesion.

Conclusion:

The following conclusions may be drawn from this work:

1. (Zn-Ni) layer deposited on carbon steel produced a great reduction and corrosion current density. For instance it was only (0.481, 0.463, 0.528) in tap water, salts solution and acidic solutions respectively.
2. Incorporated of (*m*SiC) results in more reduction in corrosion current were only (0.0615, 0.303 and 0.175) respectively in the same media.
3. Further improvement was of there (*n*SiC) particles were added, the corrosion currents density were only (0.0087, 0.226 and 0.028) respectively in the same media.
4. Nano-size particles reduced the porosity.

Tables:

Table (1) Chemical composition of the sample used.

C	Si	Mn	Cr	Fe
0.12	0.17	0.65	0.04	Rem

Table (2) Components of plating solution, [2,3].

Solution	Chemical composition	Condition of Deposition
Zn-Ni	ZnCl ₂ =83.33 g/l NiCl ₂ .6H ₂ O=40 g/l H ₃ BO ₃ =25 g/l KCl=210 g/l	pH = 5.5 Temp=25°C. Coating time= 60 min. Nickel Anodes=(99.9%) Current density=2.5 (Amp/dm ²)
Zn-Ni-μSiC	ZnCl ₂ =83.33 g/l NiCl ₂ .6H ₂ O=40 g/l H ₃ BO ₃ =25 g/l KCl=210 g/l μSiC=32 g/l Microscale , d << (73) μm	pH = 5.5 Temp=25°C. Coating time= 60 min. Nickel Anodes=(99.9%) Current density=2.5 (Amp/dm ²)
Zn-Ni-nSiC	ZnCl ₂ =83.33 g/l NiCl ₂ .6H ₂ O=40 g/l H ₃ BO ₃ =25 g/l KCl=210 g/l nSiC=32 g/l Nanoscale , d << (70-100) nm	pH = 5.5 Temp=25°C. Coating time= 60 min. Nickel Anodes=(99.9%) Current density=2.5 (Amp/dm ²)

Table (3) Chemical composition of the deposited layers.

Coating layer	element	Element percentage
Zn-Ni	Zn	86.2
	Ni	13.8
Zn-Ni-μSiC	Zn	81.3
	Ni	12.8
	μSiC	5.9
Zn-Ni-nSiC	Zn	81.5
	Ni	13.3
	nSiC	5.2

Table (4) Corrosion currents densities and corrosion potentials of deposited layers.

Media	Coating layers	Corrosion current density (μA/cm ²)	Corrosion potential (-mV)
Tap water	—	38.20	720.5
	Zn-Ni	18.29	790.9
	Zn-Ni- <i>m</i> SiC	2.35	513.3
	Zn-Ni- <i>n</i> SiC	0.332	555.6
(3%NaCl)	—	46.60	700.3
	Zn-Ni	21.60	361.8
	Zn-Ni- <i>m</i> SiC	14.14	636.6
	Zn-Ni- <i>n</i> SiC	10.57	490.2
(3%HCl)	—	7660	476.1
	Zn-Ni	4050	489.2
	Zn-Ni- <i>m</i> SiC	1340	514.2
	Zn-Ni- <i>n</i> SiC	215.86	524.8

Table (5) surface roughness values for layers coated:

Layers coated	Average values(μm)
Zn-Ni	0.47
Zn-Ni- <i>m</i> SiC	0.86
Zn-Ni- <i>n</i> SiC	0.63

Table (6) effect of SiC size on corrosion current.

Layers coated	Current density($\mu\text{A}/\text{cm}^2$)
Zn-Ni	18.29
Zn-Ni- <i>m</i> SiC	2.35
Zn-Ni- <i>n</i> SiC	0.233

Figures:

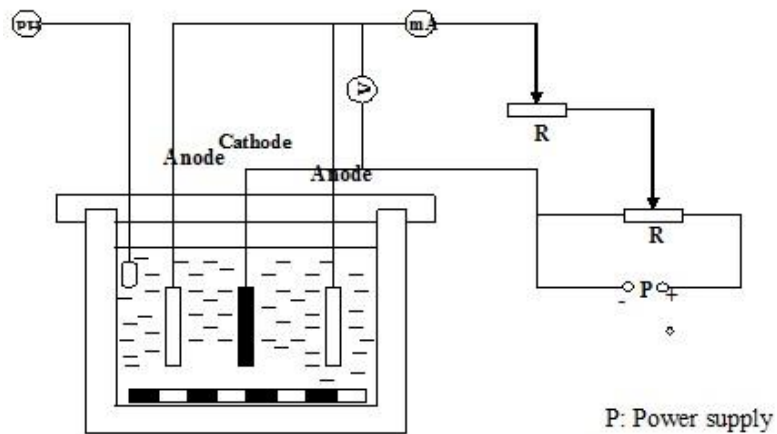


Figure (1) electroplating cell.

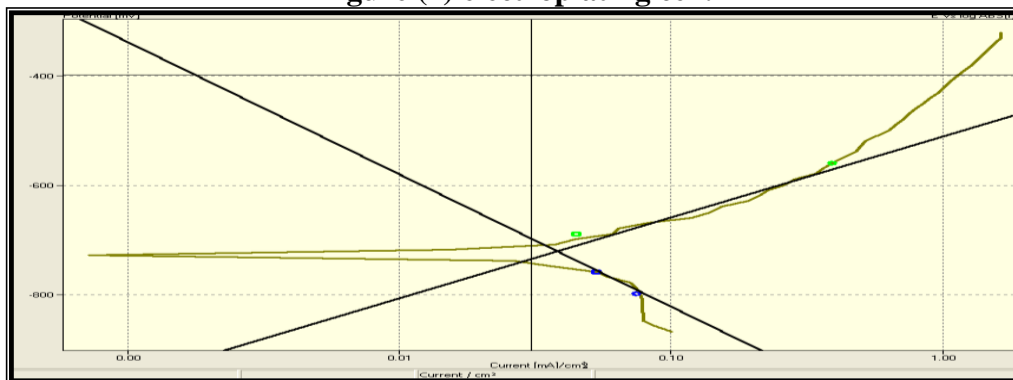


Figure (2) Corrosion behavior of carbon steel samples in tap water.

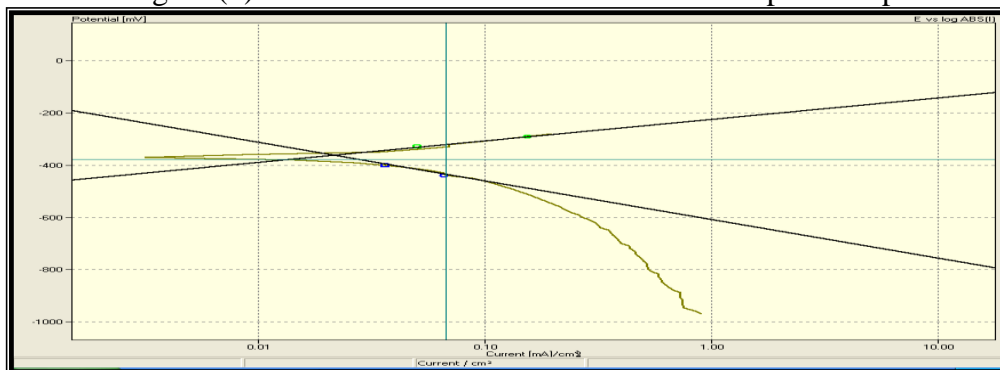


Figure (3) current density of carbon steel in NaCl.

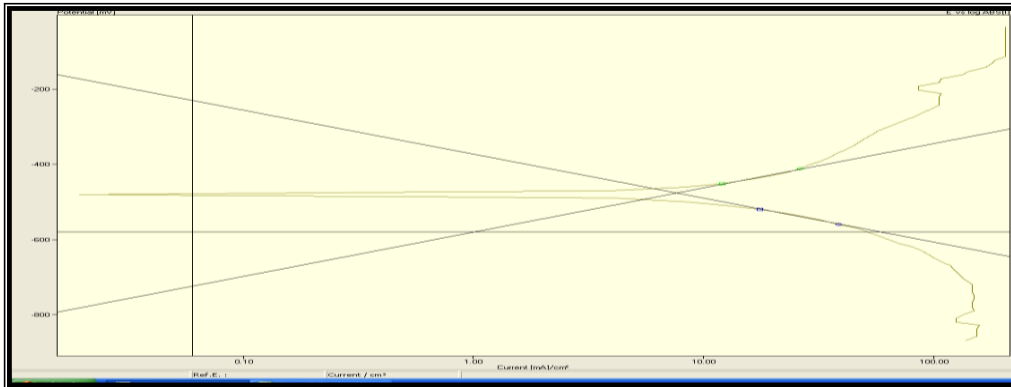


Figure (4) current density of carbon steel HCl.

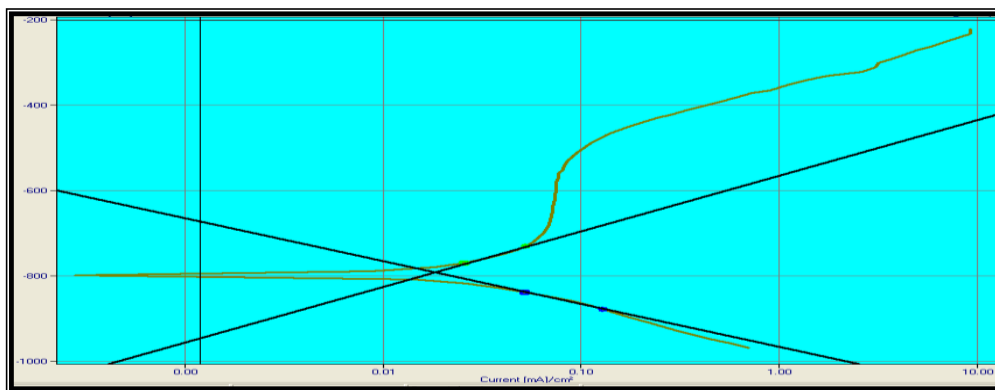


Figure (5) current density of carbon steel coated by (Zn-Ni) in tap water.

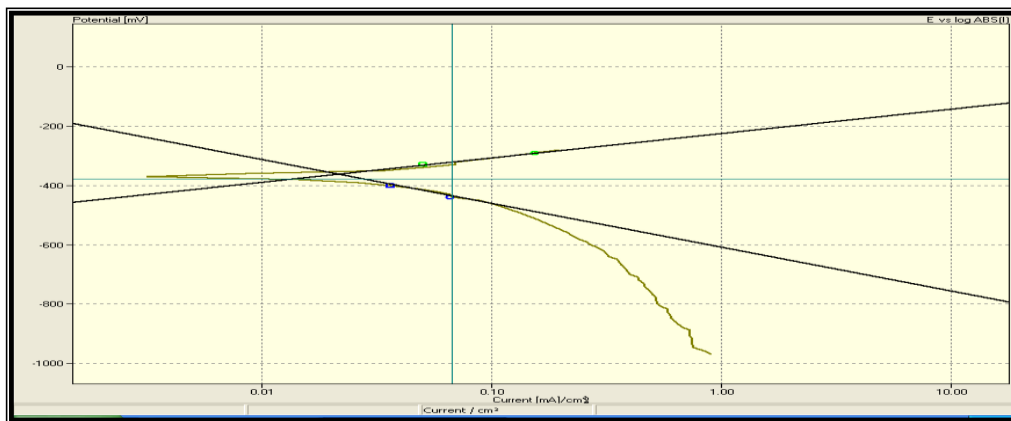


Figure (6) current density of carbon steel coated by (Zn-Ni) in NaCl.

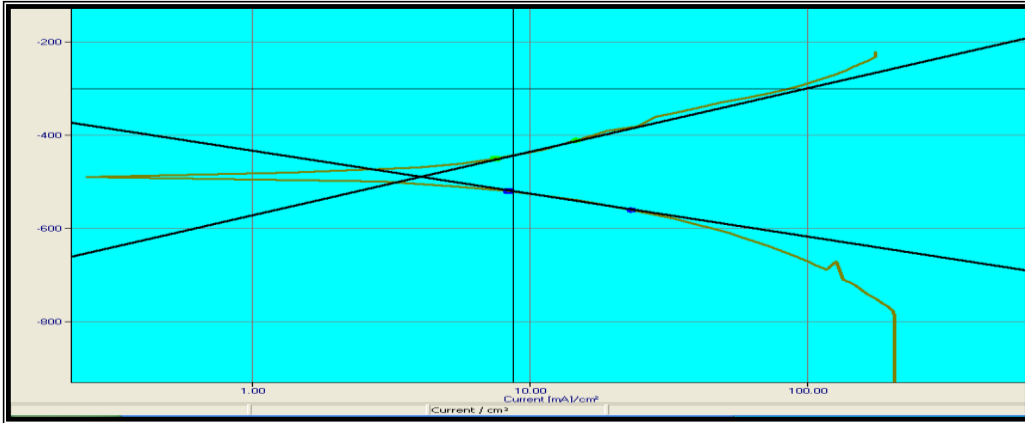


Figure (7) current density of carbon steel coated by (Zn-Ni) in HCl.

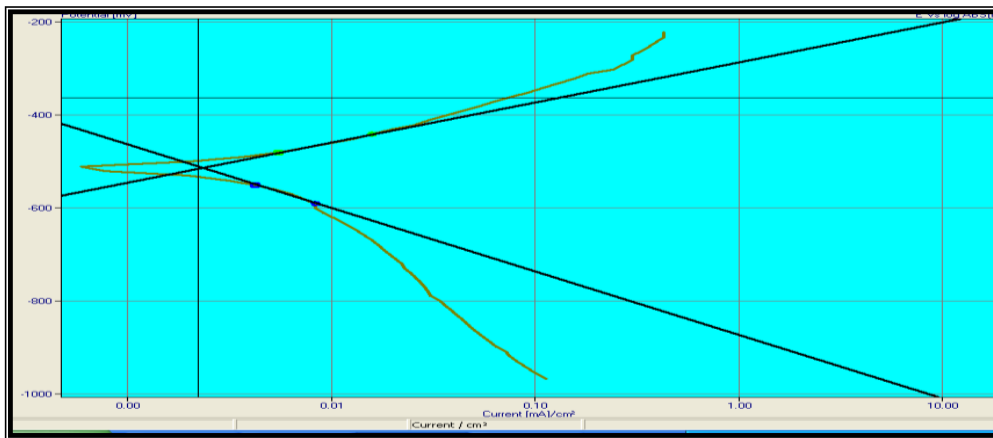


Figure (8) current density of carbon steel coated by (Zn-Ni- μ SiC) in tap water.

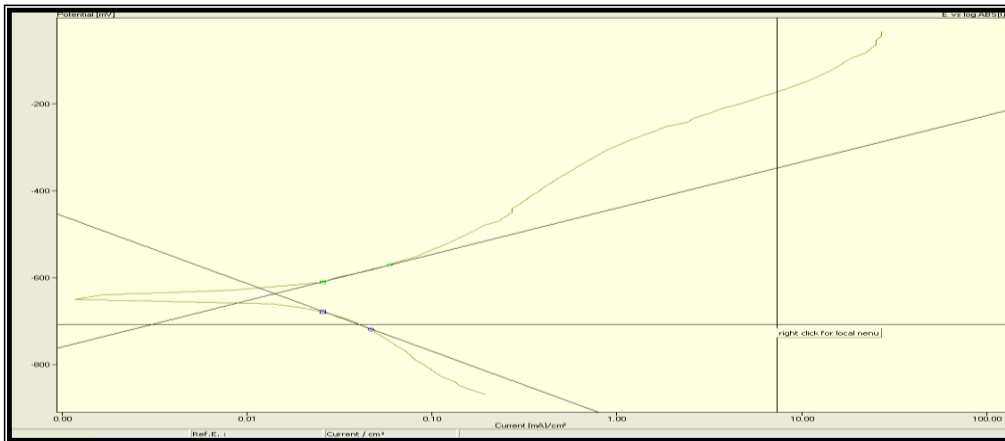


Figure (9) current density of carbon steel coated by (Zn-Ni- μ SiC) in NaCl.

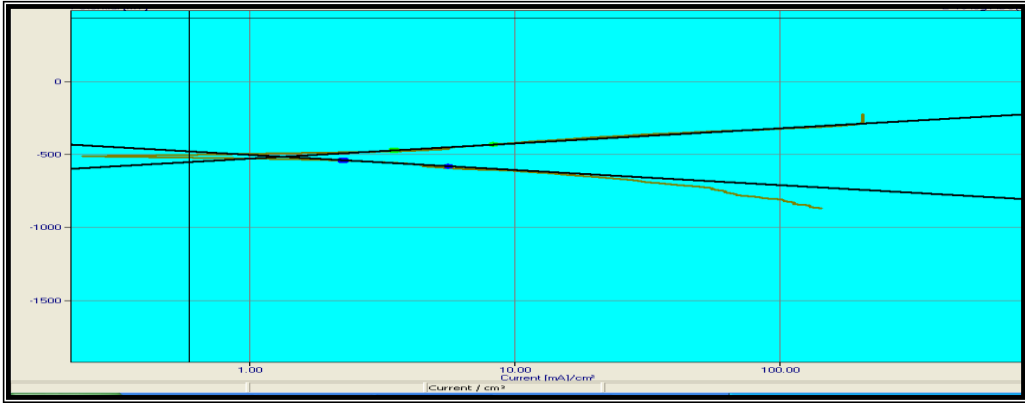


Figure (10) current density of carbon steel coated by (Zn-Ni- μ SiC) in HCl.

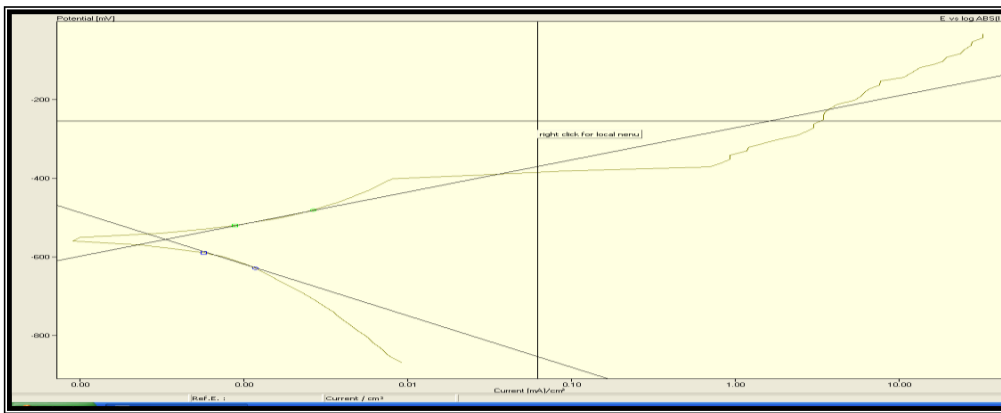


Figure (11) current density of carbon steel coated by (Zn-Ni-nSiC) in tap water.

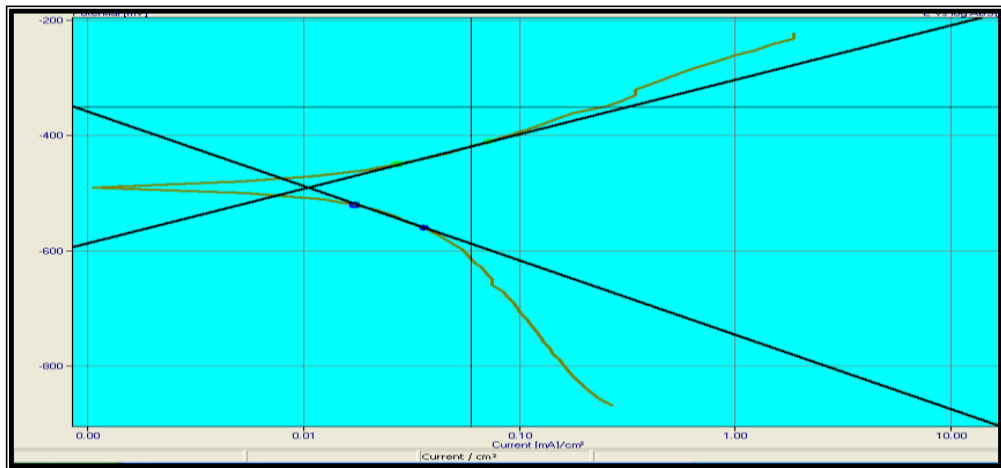


Figure (12) current density of carbon steel coated by (Zn-Ni-nSiC) in NaCl.

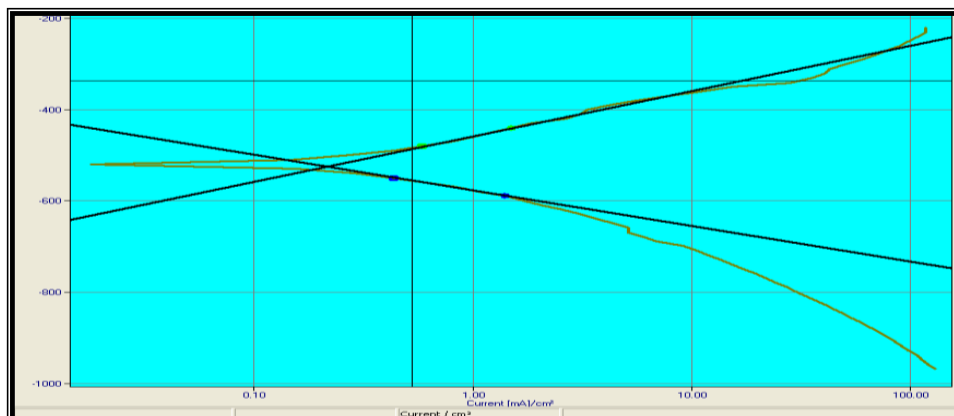


Figure (13) current density of carbon steel coated by (Zn-Ni-nSiC) in HCl.

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