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Evaluation of Structural and Physiochemical Properties of Zn/Ni Nanocomposite for Improving Corrosion Resistance of Stainless Steel for Industrial Applications

M Vijayaprakash, S Surendhiran, N Guruprasath, R Suriyaprabha, PR Senthilmurugan
Centre for Nano Science and Technology, K. S. Rangasamy College of Technology Tiruchengode, Tamil Nadu, India

ABSTRACT

Zn/Ni nanocomposite coating on Stainless Steel (SS) was prepared by Sol-Gel method. The prepared nanocomposite was used to coating on the stainless steel (SS) by doctor's plate coating method. The corrosion study was done by using the prepared Zn/Ni nanocomposite. The analysis of electrochemical impedance spectroscopy (EIS) and Linear Sweep Voltammetry (LSV) was made in 3.5% NaCl solution (neutral) and also on the HCl solution (acid). The Characterization of the Zn/Ni nanocomposite was carried out in XRD, SEM, FTIR, XRF and so on. XRD reveals the Zn/Ni nanocomposite with an average crystallite size of 17 nm. The Electrochemical impedance Spectroscopy (EIS) and Linear Sweep Voltammetry (LSV) confirms that the corrosion resistance was enhanced for the Zn/Ni nanocomposite coated Stainless Steel (SS) in compared with the bare Stainless Steel (SS) plate. Thus the prepared Zn/Ni nanocomposite will be used as a corrosion inhibitor in various industries.

Keywords : Zn/Ni nanocomposite, Linear Sweep Voltammetry, Corrosion Inhibitor.

I. INTRODUCTION

Nanomaterials based coatings are investigated as physical obstruction to safeguard metals surfaces alongside consumption and acquired powerful and far and wide applications in the field of metal assurance [1, 2]. Among all of natural coatings, ZnO, NiO, Al2O3 are broadly used because of their unrivaled synthetic idleness, remarkable bond to substrate, electrical properties and great mechanical properties. Out of the thought for wellbeing and conditions, eco-accommodating ZnO and NiO are getting increasingly more consideration [3]. Nevertheless, the anti-corrosion property of nanomaterials are greatly restricted by micropores, which are inevitably produced because of solvent evaporation and are paths for electrolyte permeation thus leading to low barrier properties. So as to improve the corrosion resistance capability of nanomaterials coatings, many challenges have been done by introducing different doping for example NiO, SnO_2, and Al_2O_3 [4-6].

To secure different pieces of the machines and body of the ship from corrosion in a salted and damp environment, its steels, as the basic building blocks, must be either coated with a layer of paint or galvanization on the surface of the metal [7]. These paint or electrify layers typically contain Zn to fill in

as a defensive layer. As Zn is more electronegative than Fe, it is more ideal to shape ZnO first and henceforth keeping the O_2 from diffusing into layers of metal surfaces. Nonetheless, as the Zn exhausts, the consumption of the steel will in the end happen. The lifetime of these excited layer and paints differs, going from a couple of months to a couple of years. As of late, Zinc and Nickel nanocomposite, as the most grounded and most slender material that offers a wide scope of potential outcomes in the electrical, optical, and biochemical field has shown that through the fuse with paints, it can shield metals from consumption in amazingly unforgiving climate and a couple of times longer than the ordinary stain covering [8-9].

In this research work, Zinc and Nickel based nanocomposite was prepared by solgel technique. The prepared Zn/Ni nanocomposite was coated on SS plate to improve the corrosion resistance under various electrolytes. The electrochemical property of the prepared Zn/Ni nanocomposite has been read extravagantly for industrial applications.

II. Experimental Details

2.1 Materials

All the chemicals: Zinc nitrate (99% purity), Nickel nitrate hexahydrate (99% purity), Sodium hydroxide (98% purity) (for the synthesis of Zn/Ni nanocomposite), Sodium Chloride (99%), Hydrochloric acid used for the preparation of electrolytes and Polyvinylidene fluorides (PVDF), N-methyl pyrrolidine (NMP) were used for coating purposes.

2.2 Synthesis of Zn/Ni nanocomposite

The Zn/Ni nanocomposite was prepared by sol-gel method. 0.5 M Zinc nitrate was dissolved in DD water and 0.5 M of Nickel nitrate was dissolved in DD water. The Nickel nitrate solution was added drop-wise in the Zinc nitrate solution. After that the reducing agent Sodium hydroxide was added to reduce the precursor solution to oxide format. A light green colour gel is formed. The solution was allowed to dry at 100 ℃. Next it will be calcinated at 350 ℃ and grinded with the mortar and pestle to make them fine powders. The finally obtained nanoparticles were named as Zn/Ni nanocomposite.

2.3 Sample preparation for electrochemical studies

The Zn/Ni nanocomposite was well grinded using mortar and pestle. A small amount of PVDF was added to the nanocomposite and grinded well. After N-methyl pyrrolidine was added and make them as a paste-like substance. The paste was coated on SS plate by using the doctor's plate coating method. It was allowed to drying for 1 h in a hot air oven. The figure 1 shows systematic details for preparation and coating process on SS plate.

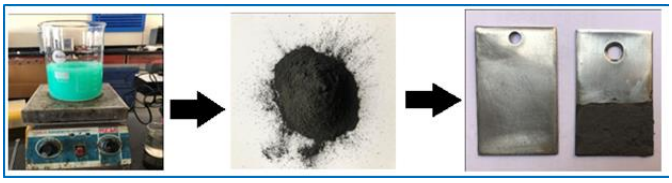

Figure 1. Synthesis and coating process of Zn/Ni nanocomposites

III. Results and Discussion

3.1 X-Ray Diffraction Analysis

The Zn/Ni nanocomposite was characterized by using a powder X-ray diffractometer (XRD; X'Pert PRO, PANalytical, Almelo, the Netherlands). The figure 2 shows the XRD spectra of Zn/Ni nanocomposite. The observed XRD pattern of the prepared Zn/Ni nanocomposite are reveals the presence of crystalline nature. The XRD patterns are strongly matched with standard JCPDS card. This XRD pattern shows the significant amount of broadening which is a characteristic of Zn/Ni nanocomposite. The XRD pattern exhibit diffraction peaks at 2θ are 36.2°, 31.7° and 43.41° indexed with their (hkl) values of (101), (100) and (200) respectively. The observed diffraction of the prepared

material shows the clear formation of Zn/Ni nanocomposite. The crystalline size can be calculated by using the Debye-Scherer formula [10].

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

Where λ is the wavelength, β is the full width at half maximum and θ is the angle obtained from 2θ values corresponding to maximum intensity peak in XRD pattern. The calculated crystalline size of Zn/Ni nanocomposite is 17.6 nm.

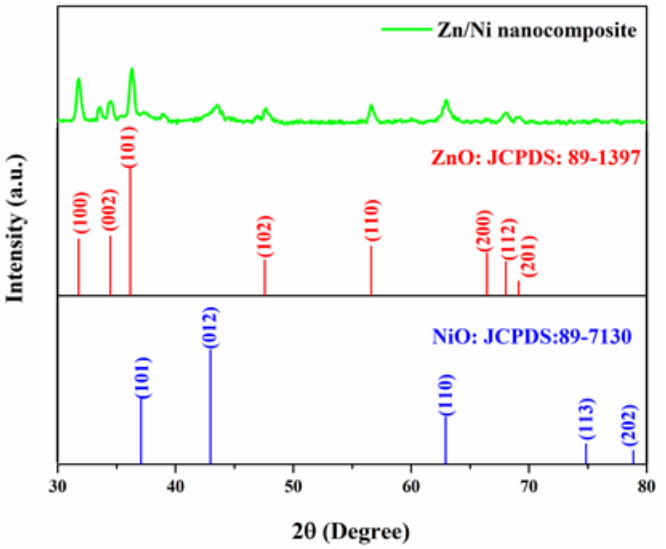

Figure 2. XRD Pattern of Zn/Ni nanocomposites

3.2 FTIR Analysis

The FTIR spectra of the Zn/Ni nanocomposite at room temperature was shown in figure 3. The FTIR spectrum was analyzed in the range of 400 cm^{-1} to 2800 cm^{-1} using FTIR spectrometer (Spectrum 100; USA). The FTIR shows the characteristic peaks at 459, 621, 838, 1119, 1202, 1388, 1641, 2080 and 2429 cm^{-1}. The bending at 459 cm-1 reveals that the presence of Zn-O. The weak bend around 1641 cm-1 to 2429 cm-1 corresponds to O-H bending it related to water absorbed. The bend at 1388 cm-1 is corresponds to the C=O stretching [11, 12].

3.3. Elemental analysis (XRF analysis)

The XRF study is used to analyze the quantitative elemental distributions of SS plate and Zn/Ni nanocomposite using EDX-700 spectrometer, Shimadzu, Japan. In this table the ZnO is presence of 48% and the NiO presence is 47%. It confirms that this is the Zn/Ni nanocomposite and it was contain equal amount of ratio. Table 1 and table 2 shows the XRF elemental distributions of SS and Zn/Ni nanocomposite.

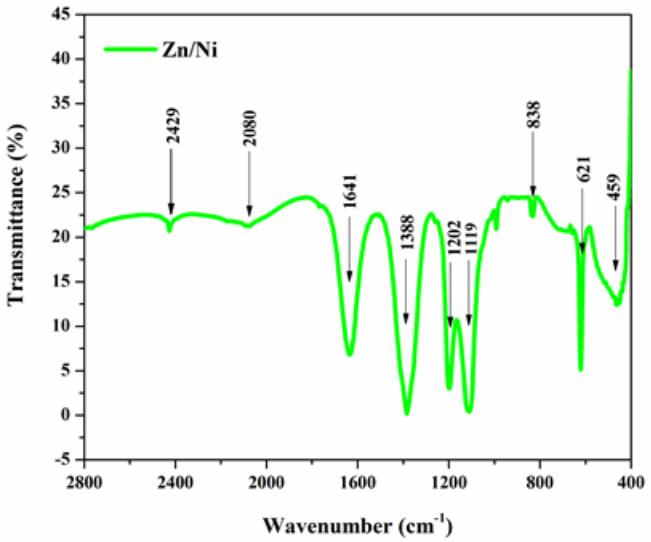

Figure 3. FTIR Spectra of Zn/Ni nanocomposite

Table 1. Quantitative analysis of SS plate used in this work

Sample	Analyte	Result	Line
SS Plate	Fe	58.153	FeKa
	Cr	17.465	CrKa
	Al	16.512	AlKa
	Ni	5.761	NiKa
	Mn	1.448	MnKa
	S	0.661	SKa

3.4 UV-Visible Spectroscopy

The UV-Vis spectra of Zn/Ni nanocomposite was shown in the figure 4.The optical absorbance of the prepared Zn/Ni nanocomposite was measured in the range of 180-800 nm using UV-Vis spectrophotometer (Cary 8454; Agilent, Singapore).

The absorption peak of NiO is observed at 199 nm and 213 nm. No other absorbance peaks are noticed in the UV-Vis spectra. The energy band gap was calculated by Tauc relationship which is given below [13],

$$(\varepsilon h\nu) = C(h\nu - Eg)^{n}$$

Here, C is a constant, ε is molar extinction coefficient, Eg is the average band gap of the material and n depends on the type of transition.

Table 2 Quantitative analysis of the prepared Zn/Ni Nanocomposites

Sample	Analyte	Result	Line
Zn/Ni nanocomposite	ZnO	50.838 %	ZnKa
	NiO	49.162 %	NiKa
	Total	**100 %**	

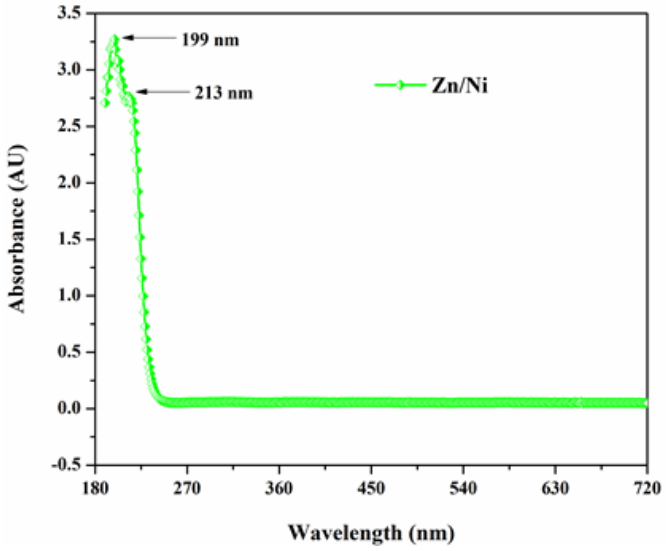

Figure 4. UV-Vis spectra of Zn/Ni nanocomposite

The calculated energy band gap for Zn/Ni nanocomposite is 3.1 eV. According to Quantum confinement effect, the UV –Vis absorption spectrum and band gap of the prepared Zn/Ni composite materials clearly depicts the crystalline size of the prepared Zn/Ni nanocomposite.

3.5 Scanning electron microscope

Figure 5 shows the morphological images of the prepared Zn/Ni nanocomposite using Quanta FEG 250, Germany. The SEM image clearly shows the agglomerated morphology and uniform distributions of Zn and Ni ions in the prepared materials. In the agglomerated morphology, the presence of cubic and rod like structures are clearly shown in SEM images. The particle size of Zn/Ni nanocomposite is ranges from 20-30 nm which was clearly matched with average crystalline size of the material obtained from XRD studies.

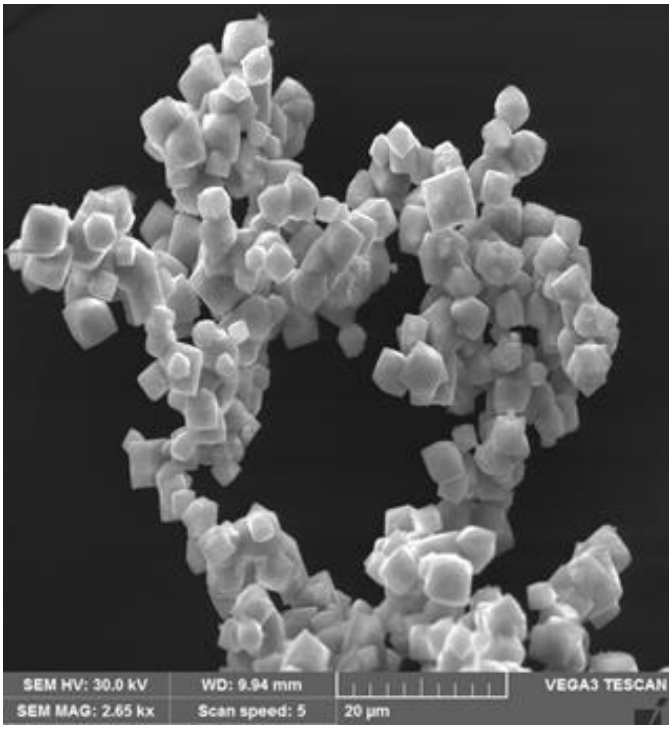

Fig. 5. SEM images of Zn/Ni nanocomposites

Surface images of the bare and Zn/Ni nanocomposites coated SS plates are shown in fig 6. The images are captured by using 40X lens microscope. These images show the surface scratches of the plates.

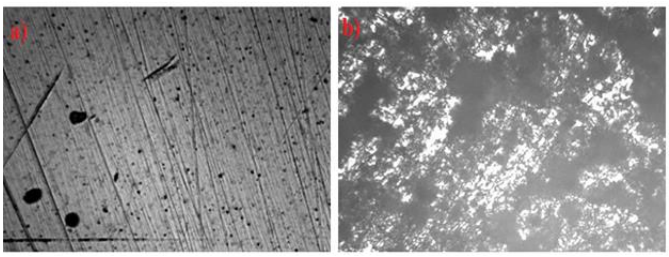

Fig 6. Optical images of SS plate and Zn/Ni composite coated SS plate

3.6 Electrochemical Corrosion Studies

The Figure 7a shows the electrochemical impedance spectra of the SS and Zn/Ni nanocomposite coated SS plates. The EIS studies were carried out in 3.5% NaCl electrolyte using electrochemical work station (Autolab, PGSTAT, and Metrohm, Netherlands). The semi-circle was not completely formed. The analysis point may be not enough to complete the formed semi-circle. The arc for the semi-circle of the Zn/Ni nanocomposite coated SS plate was very high than bare SS plate which shows the improved electrical properties of Zn/Ni coating on SS plate. As from the EIS plot, we can conclude that the electrical conductivity of the Zn/Ni coated plate shows greater than the uncoated plate.

In Figure 7b, the tafel plot for the bare SS plate and the Zn/Ni nanocomposite coated SS plate in 3.5% NaCl electrolyte were shown. The tafel plots potential shift is shifted towards right; it shows that the corrosion resistance increases and the corrosion rate decreases for the coated plate. The Zn/Ni nanocomposite coating on SS plate acted as physical barrier for preventing corrosion from the Na and Cl ions. So the Zn/Ni coated SS plate shows the better corrosion resistance under 3.5% NaCl electrolyte medium [14, 15].

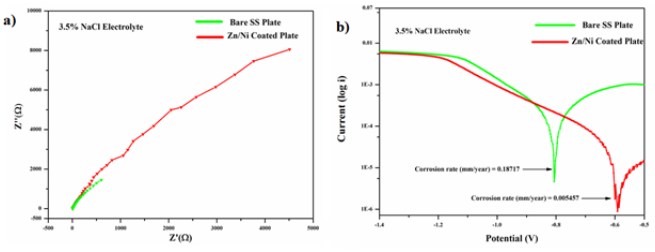

Figure 7 a) Electrochemical impedance spectra, Figure 7 b) Tafel plot for the SS plate and Zn/Ni nanocomposite coated SS plate under 3.5% NaCl

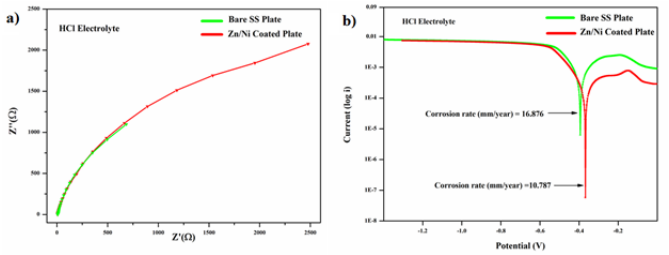

Figure 8 a) Electrochemical impedance spectra, Figure 8 b) Tafel plot for the SS plate and Zn/Ni nanocomposite coated SS plate under 1M HCl

Figure 8 (a and b) shows the EIS and Tafel plot of the bare SS plate and the Zn/Ni nanocomposite coated SS plate under 1M HCl electrolyte. The Tafel plots potential is shifted towards anodic side (positive side), which means that the corrosion resistance increases and the corrosion rate decreases for the coated plate. The calculated potentiodynamic polarization parameters of bare SS and Zn/Ni nanocomposite coated SS plates were tabulated in table 3.

Table 3. Potentiodynamic polarization curve parameters obtained Tafel plot

Electrolyte	Substrate	E_{corr} (V)	I_{corr} (A/cm^2)	Polarization resistance (Ω)	Corrosion rate (mm/year)	IE %
3.5% NaCl	SS plate	804.62 0 m	16.108 0 µ	309.590	0.18717	-
	Zn/Ni-SS	595.98 0 m	469.62 0 n	2.78350	0.00545	97.10
1M HCl	SS plate	394.43 0 m	1.4523 0 m	41.5230	16.876	-
	Zn/Ni-SS	394.23 0 m	928.28 0 µ	122.330	6.787	60.19

IV. CONCLUSION

Zn/Ni nanocomposite was prepared by the sol-gel method and its structural, functional groups, optical, and hardness properties are studied by various techniques. XRD revealed that hexagonal and cubic nature for ZnO and NiO respectively with an average crystalline size of 17.6 nm. The UV-Vis spectra

confirm the presence of NiO with band gap energy of 3.1eV. The presence of functional groups was observed by using FTIR. The XRF revealed the Zn/Ni nanocomposite present in equal ratio. The Linear Sweep Voltammetry (LSV) and Electrochemical Impedance Spectroscopy (EIS) confirm that the Zn/Ni nanocomposite has superior anticorrosion capability. As observed from the obtained results, the prepared materials has been employed for potential candidate to prevent the corrosion happenings on metal surfaces due to environmental conditions.

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