Yttrium doped ZnO nanoparticles towards corrosion protection epoxy nanocomposite coatings in neutral and acidic medium

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Abstract

In the present study, synthesized pure and Yttrium (0.5, 1.0, 1.5, 2.0 and 2.5 mM) doped Zinc Oxide (YZO) nanoparticles by chemical precipitation method. The size effect of Zinc oxide nanoparticle under Yttrium acetate precursor molar concentration were investigated by various characterization techniques. X-ray diffractogram asserts the hexagonal wurtzite structure of ZnO nanoparticles. The average crystallite size was found to be 22 – 17 nm. The FTIR and Raman spectrum inscribed the chemical composition and vibrational frequencies of the synthesized samples. The hexagonal shape, surface morphology, particle size and elemental composition of the samples were analysed by FESEM, HRTEM and EDAX. The optical bandgap energy was estimated in the range of 3.148–3.175 eV. PL spectra of yttrium doped ZnO nanoparticles at various concentration exhibit a strong UV emission band and green emission band. The anticorrosive property of nanoscopic size (17 nm) YZO/epoxy nanocomposite was studied by electrochemical impedance spectroscopy (EIS) technique in both neutral and acidic medium. Epoxy/YZO nanocomposites were prepared using different loadings (0.05, 0.10 and 0.15 wt %) of yttrium doped ZnO nanoparticles. Epoxy/YZO nanocomposites were applied on mild steel substrates. The acquisition of yttrium doped ZnO into the plain epoxy coating materially increased the charge transfer resistance R_{ct} by 3.5 times in oxalic acid solution as against epoxy/ZnO coating. The synthesized sample has also displayed excellent antimicrobial activity against gram positive and gram-negative bacteria. This encapsulates that the YZO nanoparticles are a potential eco-friendly, antibacterial and anti-corrosive fillers in coat on mild steel.

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Tables

Table 1: Structural parameters of ZnO nanoparticles and Y doped ZnO nanoparticles: Standard JCPDS Card no. (36-1451) $a = 3.249 \text{ \AA}$ and $c = 5.206 \text{ \AA}$

Y dopant concentration	Average crystalline size (nm)	Lattice parameter		c/a ratio	Unit cell volume v	Crystallite volume (D) ³ (nm) ³	Micro strain $\epsilon \times 10^{-3}$	Bond length (Zn-O) (Å)	Degree of distortion R
		a (Å)	c(Å)						
0.00 mM	22.78	3.2335	5.1918	1.6056	47.010	1.1838	1.1944	1.9695	1.0170
0.50 mM	26.38	3.2494	5.2069	1.6024	47.611	1.8370	1.2990	1.9776	1.0190
1.00 mM	23.40	3.2479	5.2047	1.6024	47.548	1.2818	1.4646	1.9767	1.0190
1.50 mM	23.11	3.2511	5.2069	1.6015	47.661	1.2345	1.4831	1.9783	1.0196
2.00 mM	17.61	3.2526	5.2156	1.6035	47.786	5.4610	1.7298	1.9800	1.0183
2.50 mM	37.60	3.2432	5.1977	1.6026	47.346	5.3180	0.9115	1.9739	1.0189

Table 2: EIS and corrosion parameters for YZO/epoxy coated mild steel in 3% NaCl solution after 2 hours immersion

S.No	Materials	R_{ct} (Ω)	$-E_{corr}$ (mV)	I_{corr} (mA/cm ²)	Corrosion rate (mm/year)
1.	A (0.05 wt% YZO)	1289	533.640	10.272	0.000119
2.	B (0.10 wt% YZO)	7734	388.052	05.114	0.0000594
3.	C(0.15 wt% YZO)	3289	644.682	08.353	0.0000970

Table 3: EIS and corrosion parameters for Epoxy-ZnO/YZO coated mild steel in 3% oxalic acid solution after 2 hours immersion

S.No	Materials	R_{ct} (Ω)	$-E_{corr}$ (mV)	I_{corr} (mA/cm ²)	Corrosion rate (mm/year)
1.	Epoxy-ZnO	1424	498.223	13.951	0.00016
2.	Epoxy-YZO	4970	444.154	07.804	0.0000906

Table 4: Comparison of the corrosion parameters of different nanomaterial coating

Sample	Substrate	Medium	$-E_{corr}$ (V)	I_{corr} (μ A/cm ²)	Reference
Graphene oxide	Mild steel	3.5 wt % NaCl solution	0.455	0.22	[57]
Titanium nanoparticle	Mild steel	1 M HCl	0.522	58.6	[75]
CeO ₂ doped ZnO nanoparticles Zn-composite coating	Mild steel	3.5 wt % NaCl solution	1.093	0.1040	[76]
ZnO nanoparticles	Stainless steel 316 L	Mild steel	0.33815	2.28	[77]
Zn-1% Mn doped TiO ₂ nanoparticle composite	Mild steel	Mild steel	0.961	5.154	[78]
CSA doped polyaniline SnO ₂ nanocomposite	A-36 Carbon steel	1 M HCl	0.271	0.0048	[79]
Yttrium doped ZnO nanoparticles	Mild steel	Oxalic acid	4.441	0.0078	Present study

Figures

Figure 1

a (A-F) Typical XRD patterns of rare earth element (REE) yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

b (A-F) Diffraction peak broadening

Figure 2

a Lattice parameter "a" and "c" values with various concentration of Yttrium

b The variation of full width half maximum (FWHM) and average crystalline size of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles as a function of Y concentration

Figure 3

(A-F) FTIR spectra of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 4

(A-F) FT-RAMAN spectra of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 5

(A-F) FESEM images of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 6

(A-B) EDAX spectrum of yttrium (0.0 and 2.0 mM) doped ZnO nanoparticles

Figure 7

HRTEM images and particle size distribution histogram of (A-C) pure ZnO nanoparticles (D-F) yttrium 2.0 mM doped ZnO nanoparticles

Figure 8

HRTEM image and interplanar lattice fringes and SAED pattern of (A-C) pure ZnO nanoparticles and (D-F) yttrium 2.0 mM doped ZnO nanoparticles

Figure 9

(A-F) UV-Visible absorption spectra of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 10

(A-F) Tauc plot of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 11

(A-F) Photoluminescence spectra of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles

Figure 12

Nyquist plots of (A) 0.05 wt % (B) 0.10 wt % and (C) 0.15 wt % YZO/epoxy nanocomposite coated mild steel substrates in 3 wt % NaCl solution after 2 hour immersion

Figure 13

Variation in R_{ct} versus weight percentage of YZO nanoparticles

Figure 14

Tafel plots of (A) 0.05 wt % (B) 0.10 wt % and (C) 0.15 wt % YZO/epoxy nanocomposite coated mild steel substrates in 3 wt % NaCl solution after 2 hour immersion

Figure 15

Nyquist plots of (A) 0.10 wt % epoxy/ZnO (B) 0.10 wt% epoxy/ YZO nanocomposite coated mild steel substrates in 3 wt % oxalic acid solution after 2 hour immersion

Figure 16

Tafel plots of (A) 0.1 wt % epoxy/ZnO (B) 0.1 wt% epoxy/YZO nanocomposite coated mild steel substrates in 3 wt % Oxalic acid solution after 2 hour immersion

Figure 17

Hierarchy of corrosion protection mechanism of epoxy/YZO nanocomposite on mild steel

R_{ct} – Charge transfer resistance

C_{dl} - Double layer capacitance

Figure 18

Equivalent circuit model for epoxy/YZO nanocomposite coating on mild steel

Figure 19

Antibacterial activity of yttrium (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles against gram positive bacteria (A-B) and gram negative bacteria (C-D)

Figure 20

Graphical representation of zone of inhibition (mm) of (0.0 , 0.5 , 1.0 , 1.5 , 2.0 and 2.5 mM) doped ZnO nanoparticles