Cathodically Electrodeposited Nitrogen-Doped Carbon Dots-Acrylic Nanocomposite Coatings: A Dual-Function Corrosion Barrier and Real-Time Corrosion Sensor

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Bath Characteristics

The prepared bath for the electrodeposition of the Ac0NCD, Ac0.5NCD, Ac1NCD and Ac1.5NCD were characterized to understand the nature of the bath and to optimize the coating conditions. The most optimized bath characteristics are tabulated in **Table S1**.

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Component	Sample	Test Description	Result
Resin Bath	Prepared Resin	%NVM (120°C/1hr)	63.25%
		Viscosity on Brookfield Viscometer	5200 cP
		Acid Value (mg KOH/g)	1.39
		Amine Value	51.23
	Ac0NCD	Refractive Index	13.0
		рН (25°С)	4.78
		Conductivity (25°C)	679 μS/cm
	Ac0.5NCD	Refractive Index	12.0
		pH (25°C)	4.63
		Conductivity (25°C)	702 µS/cm
		Refractive Index	12.0
	AcINCD	pH (25°C)	4.55
		Conductivity (25°C)	721 µS/cm
	Ac1.5NCD	Refractive Index	11.0
		рН (25°С)	4.41
		Conductivity (25°C)	779 µS/cm



Fig. S1. Open circuit potential (OCP) values of the respective coatings that confirms the initiation of the corrosion process. The more negative the OCP values, faster is the initiation of the corrosion process. These trends are in confirmation with those of the Tafel data provided in the main text.



Fig S2. The pore resistance (R_p) and the charge transfer resistance (R_{ct}) offered by the respective coatings. The trends are similar to that observed by the Nyquist plots. It exhibits the enhancement of the corrosion resistance of the coatings with the optimum dosage of N-CD solution (1ml)as well as the decrease in performance when the dosage is increased (1.5ml)

Table S2. Capacitance values (C_1 and C_2) corresponding to the outer and inner layers of the coating system

Coating	$C_1(F)$	$C_2(F)$
AcONCD	6.2x10 ⁻⁴	4.8x10 ⁻⁴
Ac0.5NCD	4.6x10 ⁻⁷	1.7x10 ⁻⁷
Ac1NCD	1.0x10 ⁻⁸	2.7x10 ⁻⁹
Ac1.5NCD	7.8x10 ⁻⁷	1.6x10 ⁻⁷

This is derived from EIS fitting. The significant decrease in capacitance for the Ac1NCD formulation suggests minimal electrolyte penetration and a compact coating structure, confirming its superior corrosion resistance.

Table S3. The notations and the significance of the electrical elements used in the corrosion circuit.

Notation	Significance
R _s	Solution resistance
R _p	Charge transfer resistance
CPE ₁	Constant Phase Element (1)
C ₁	Capacitance of the constant phase element
R _{ct}	Charge transfer resistance
CPE ₂	Constant Phase Element (1)
C ₂	Capacitance of the constant phase element



Fig S3. a. XPS spectra of the NCDs confirming the presence of C, N and O; b. The N1s spectra of the N-CDs and c. The O1s Spectra of the NCDs

The visual inspection of the coated substrates under UV illumination revealed a clear loss in fluorescence intensity upon exposure to a corrosive environment, particularly in regions proximal to defect sites. This quenching effect is attributed to the interaction of Al³⁺ ions—released during the early stages of localized corrosion—with the fluorophoric sites embedded within the nanocarbon-doped coating matrix. As Al³⁺ acts as a strong fluorescence quencher, this interaction serves as an effective pre-corrosion indicator, enabling early detection even before visible delamination or pitting is observed. The progressive fluorescence decay observed in the AC1NCD and AC1.5NCD samples correlates well with their electrochemical degradation, highlighting the dual functionality of the coating system as both a protective and diagnostic layer.



Scribing and exposure to salt solution for a week

Fig.S4: UV-fluorescence of the coated samples before and after scribing and dipping in salt solution for 1 week confirming in-situ detection of corrosion via quenching of samples: a.) Ac0.5NCD to a'.); b.) Ac1NCD to b'.) and c.) Ac1.5NCD to c'.).



Fig S5: Comparison on the various aspects of anticorrosive performance of NCDs with respect to other nanoparticles.^{1–5}



Fig. S6. a.) Digital photograph image of cross-cut adhesion of the AcINCD coating depicting the 5B grade (<0-5% delamination), b.) Enlarged Digital Photograph of the marked area; c.) the corresponding polarized optical microscope image of the similar area.

References:

- Rout, T. K.; Gaikwad, A. V. In-Situ Generation and Application of Nanocomposites on Steel Surface for Anti-Corrosion Coating. *Prog Org Coat* 2015, *79* (C), 98–105. https://doi.org/10.1016/J.PORGCOAT.2014.11.006.
- (2) Bozorg, M.; Ramezani, A. Characterization and Protective Performance of Acrylic-Based Nanocomposite Coating Reinforced with Silica Nanoparticles. *Materials and Corrosion* 2017, 68 (7), 725–730. https://doi.org/10.1002/MACO.201609347.
- Eduok, U.; Suleiman, R.; Khaled, M.; Akid, R. Enhancing Water Repellency and Anticorrosion Properties of a Hybrid Silica Coating on Mild Steel. *Prog Org Coat* 2016, *93*, 97–108. https://doi.org/10.1016/J.PORGCOAT.2016.01.006.
- Lewis, O. D.; Critchlow, G. W.; Wilcox, G. D.; Dezeeuw, A.; Sander, J. A Study of the Corrosion Resistance of a Waterborne Acrylic Coating Modified with Nano-Sized Titanium Dioxide. *Prog Org Coat* 2012, *73* (1), 88–94. https://doi.org/10.1016/J.PORGCOAT.2011.09.004.
- (5) Aboorvakani, R.; Kennady Vethanathan, S. J.; Madhu, K. U. Influence of Zn Concentration on Zinc Oxide Nanoparticles and Their Anti-Corrosion Property. *J Alloys Compd* 2020, *834*, 155078. https://doi.org/10.1016/J.JALLCOM.2020.155078.