Chemeca 2025 and Hazards Australasia
28 – 30 September, Adelaide, South Australia

Surface Charge-Driven Sustainable Marine Coatings

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ABSTRACT

Biofouling and associated corrosion is an unresolved problem that causes irreversible damage to steel marine structures worldwide that even rigorously intensifies in marine aggressive environments, posing a need for the development of sustainable protective coatings. Conventional antifouling coatings rely on toxic biocides, including copper (Cu), cadmium (Cd), and tributyltin (TBT), which were banned in 2008 due to their harmful ecological impact. This necessitates the development of environmentally friendly alternatives with dual functionality-biofouling resistance and corrosion mitigation. Zinc oxide (ZnO) has been a prominent choice in marine protective coatings to reduce corrosion and biofouling since last decade, however, properties like surface charge, structural variations, and film forming capabilities are still underexplored. A sustainable coating system is proposed in this study by incorporating ZnO nanostructures—nanoparticles (NPs), nanowires (NWs), nanoflakes (NFs), and javelin-like (Jav) structures into a biopolymer rosin matrix with negatively charged graphene oxide (GO). The ZnO structures exhibited various surface charges (+17.36 mV for NPs, -3.81 mV for NWs, +23.26 mV for NFs, and +30.43 mV for Jav), significantly influencing interfacial interactions within the coating system. The different charges of ZnO nanostructures in the self-polished coating matrix aim to destabilize the electric double layer (EDL) at the solid-liquid interface to disrupt microbial adhesion and settlement. However, the electrochemical impedance spectroscopy (EIS) and corrosion rate analysis of the prepared samples revealed that the Rosin/GO/ZnO Jav coating exhibited superior anticorrosion performance, with an impedance modulus $|Z|_{0.01Hz}$ *of* $5.93 \times 10^7\ \Omega cm^2$ *and a reduced corrosion* *rate of 9.95 × 10^{-9} mmpy (millimetres per year), significantly outperforming the uncoated substrate ($|Z|_{0.01Hz}$ of 892.32 Ωcm^2, corrosion rate of 3.78 × 10^{-2} mmpy). The high zeta potential of ZnO Jav (+30.43 mV) facilitated electrostatic interactions with GO (-32 mV), stabilizing the final zeta potential of GO/ZnO Jav at +53.75 mV. This charge-enhanced stabilization mechanism in the coating matrix restricted the corrosion causing penetration of chloride ion (Cl^-), and further disrupted microbial attachment, thereby mitigating biofouling. However, the optimized coating exhibited nearly complete corrosion resistance for 144 hours in a 3.5 wt% NaCl solution, highlighting its long-term durability in harsh environments. These results demonstrate the possible use of various ZnO nanostructures in a bio-based rosin coating as a scalable and ecologically friendly substitute to conventional toxic marine coatings. The combination of various surface-charge of ZnO nanostructures with GO and the biopolymer rosin presents a promising approach for total marine protection, in accordance with global sustainability efforts.*

KEY WORDS

Gum rosin, Zinc oxide nanostructures, Graphene oxide, anticorrosion coatings, surface charge, zeta potential

BIOGRAPHY

I am Gurleen Singh Sandhu, a PhD candidate at the School of Chemical Engineering, The University of Adelaide, under the supervision of Professor Dusan Losic and co-supervision of Dr. Md Julker Nine. My research focuses on developing functionally active charged surfaces for antibiofouling applications, with the aim of creating innovative solutions for marine environments. I completed my Bachelor of Production Engineering in India and pursued a Master of Materials Engineering at The University of Adelaide. I am passionate about advancing materials engineering, sustainability, and innovation in the area of functional coatings.

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