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Editorial: Advances in microbiologically influenced corrosion and new intelligent biomaterials design

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Editorial on the Research Topic
Advances in microbiologically influenced corrosion and new intelligent biomaterials design

In critical fields such as marine engineering, energy pipelines, shipbuilding, and biomedical applications, the long-term service reliability of materials is increasingly challenged by complex microbial environments (Xu et al., 2023). Particularly under high-humidity, nutrient-rich microecological conditions, surfaces are prone to the formation of complex biofilm structures, thereby initiating microbiologically influenced corrosion (MIC) and accelerating localized failure of metallic materials (Kuklinski and Sand, 2014; Singh, 2020). It is estimated that MIC accounts for more than 20% of the total corrosion-related losses worldwide (Machuca Suarez, 2019). This form of corrosion not only increases maintenance and replacement costs but also poses serious risks to environmental safety and human health.

MIC is essentially a typical interfacial, multifactorial corrosion process influenced by a synergistic combination of factors, including material type, microbial community composition, biofilm metabolic activity, and the local electrochemical environment (Jia et al., 2019; Telegdi et al., 2020; Wang et al., 2022). Representative anaerobic microorganisms such as sulfate-reducing bacteria (SRB) can secrete hydrogen sulfide or form conductive biofilms that directly interfere with electron transfer at the metal interface, inducing anodic dissolution and passivation film breakdown (Tripathi et al., 2021; Anandkumar et al., 2016; Dou et al., 2018). Welikala et al. demonstrated that under nutrient-rich conditions, SRB form compact nodular biofilms on steel surfaces, which lead to irregular pitting; under nutrient-deficient conditions, bacterial adhesion increases due to the demand for electrons from the metal, intensifying interfacial electrochemical heterogeneity and accelerating overall corrosion. Lu et al. (2024)

further revealed that under eutrophic seawater conditions, pitting depth on copper surfaces increased significantly, reaching up to 17.8 μm-1.8 times that under nutrient-deficient conditions. Although biofilm thickness was lower in poor media, enhanced adhesion due to starvation-induced stress expanded the electrochemical heterogeneity, highlighting a metabolism-driven corrosion mechanism (M-MIC).

In recent years, extracellular electron transfer (EET)-mediated corrosion mechanisms have attracted growing attention, particularly in studies of electroactive bacteria such as *Pseudomonas aeruginosa* and SRB (Chugh et al., 2022; Dou et al., 2019). Zhou et al. (2022) reported that overexpression of *phzH* in *P. aeruginosa* led to denser biofilm formation on 2205 duplex stainless steel, with increased phenazine (PCN) secretion promoting H_2O_2 generation and accelerating the dissolution of Cr_2O_3 passive films. This resulted in a corrosion current density of 189 nA/cm^2 and a pitting depth of 4.2 μm, indicating that *phzH* modulates the coupling between EET activity and passive film degradation. Similarly, Wang et al. (2021)) demonstrated that in riboflavin-rich environments, *Desulfovibrio ferrophilus* IS5 utilized riboflavin as an electron mediator to significantly accelerate Fe (0) oxidation and sulfate reduction, raising corrosion current density by 63% and reducing polarization resistance by 31% within hours. The corrosion rate increased from 1.03 to 1.57 mm/year, suggesting that microbial metabolic activity and electron transfer capability, rather than biomass alone, predominantly dictate corrosion behavior.

Although conventional biocides such as quaternary ammonium compounds, glutaraldehyde, and DCOIT are widely employed for MIC control in industrial systems, their effectiveness remains limited by several factors (Jones and Joshi, 2021; Wang et al., 2023; Shi et al., 2011). Biofilms act as a physical barrier that significantly impairs biocide diffusion and activity. Moreover, microbial resistance to chemical biocides is continuously increasing, resulting in reduced protection duration. Many of these compounds also exhibit environmental toxicity and bioaccumulation potential, conflicting with sustainable development goals. As such, the development of high-performance, environmentally benign, and stimuli-responsive "smart biomaterials" has emerged as a promising direction for MIC mitigation.

Recent advances have introduced novel materials—including natural antimicrobial peptides, biomimetic polypeptides, responsive polymers, and nanostructured coatings—into the MIC protection field. For instance, Yu et al. (2024) developed a chiral metal-organic framework (MOF) coating incorporating d-amino acids, Cu^{2+} ions, and nanostructures to achieve a synergistic "biofilm dispersion–chemical disruption–physical damage" mechanism. Their system reduced viable Gram-positive/negative cell counts by over 4.5 log, increased mature biofilm destruction by 1.6 log, and decreased algal adhesion by 77.8%. Pang et al. demonstrated that polyaspartic acid (PASP) and D-phenylalanine formed a dense protective film on carbon steel, suppressing SRB adhesion and reducing corrosion current density to 0.530×10^{-7} A/cm^2, with pit depth reductions approaching 90%. Yang et al. employed a hydrogel copolymer of SBMA and HEMA loaded with D-amino acids and gentamicin to enhance anti-biofilm efficacy, achieving over 90% inhibition by targeting both bacterial wall integrity and metabolic activity. Sun et al. (2025) synthesized the peptide Tcs, which significantly enhanced THPS efficacy under SRB-rich conditions, reducing corrosion current density to 0.18–0.19 μA/cm^2 and lowering corrosion rates by 90% through a synergistic cationic–hydrophobic action. Xu et al. observed severe pitting (>375 μm) on 13Cr steel in seawater in the presence of *D. ferrophilus* IS5; however, co-application of green biocide THPS and dispersive peptide A effectively disrupted biofilm structure and reduced surface corrosion current by over 90%, demonstrating a "disperse–penetrate–kill" strategy applicable to both marine steels and copper alloys. Additionally, self-healing polymer networks and sensor coatings capable of responding to microbial metabolites (e.g., pH, H_2S) offer promising avenues for intelligent, real-time corrosion monitoring and protection (Kardar et al., 2016; Bekas et al., 2016; Ni et al., 2021; Fu et al., 2013; Qian et al., 2017).

This study aims to explore the interdisciplinary frontier between microbiologically influenced corrosion and the development of novel intelligent biomaterials. By leveraging insights from corrosion electrochemistry, biomaterials science, microbial ecology, and interfacial engineering, this work seeks to advance material strategies from passive resistance to active prevention and smart feedback, thereby laying the theoretical and technological foundation for the next-generation of MIC-resistant materials.

Author contributions

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