



# Electrochemical Performance of Carbide Coatings for Corrosion Resistance in Chloride Environments

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This study presents a novel electrochemical comparison of WC–Co and Cr<sub>3</sub>C<sub>2</sub> coatings on steel substrates, addressing a critical gap in benchmarking corrosion resistance under controlled alkaline conditions. In 3.5% NaCl, potentiodynamic polarization revealed corrosion rates of 0.065668 mm/year for uncoated steel, 0.023323 mm/year for WC–Co, and a significantly lower 0.007667 mm/year for Cr<sub>3</sub>C<sub>2</sub>. The enhanced performance of Cr<sub>3</sub>C<sub>2</sub> is linked to its superior passivation and microstructural stability. These findings establish a unified framework for evaluating coating efficacy in aggressive environments and offer actionable guidance for material selection in corrosion-critical sectors such as offshore, mining, and chemical processing.

## INTRODUCTION

Corrosion is a pervasive and costly phenomenon that leads to the gradual degradation of metals exposed to aggressive environments, such as those containing moisture, oxygen, and chloride ions.<sup>1,2</sup> Particularly in sectors like marine, chemical processing, and mining, corrosion poses serious risks by accelerating equipment failure, increasing maintenance costs, and compromising safety.<sup>3</sup>

Although materials such as duplex stainless steels (DSS), notably DSS2205, offer improved corrosion resistance due to their dual-phase microstructure and excellent mechanical properties,<sup>4–6</sup> their performance can degrade in environments with high chloride concentrations.<sup>7,8</sup> To address these limitations, advanced surface engineering approaches—particularly protective coatings—are increasingly applied to extend the service life of DSS components.<sup>9,10</sup>

Recent studies have demonstrated that hybrid or composite coatings can further enhance the corrosion resistance of DSS2205 by combining the benefits of different materials.<sup>11,12</sup> These coatings not

only improve barrier properties but also enhance passivation and mechanical durability, making DSS2205 more suitable for deployment in highly aggressive environments. Atmospheric plasma spray (APS) is a widely used thermal spray technique for depositing such protective coatings. APS enables the formation of dense, adherent, and low-porosity cermet coatings with customizable microstructures.<sup>12–14</sup> Its ability to produce uniform splats, strong interlamellar bonding, and nanostructured layers contributes to improved corrosion performance.<sup>15–17</sup> Among the materials used, WC–Co is valued for its hardness and toughness, but can suffer from selective cobalt binder leaching in acidic conditions.<sup>18,19</sup> Cr<sub>3</sub>C<sub>2</sub>-based coatings, in contrast, provide inherently higher corrosion resistance due to the formation of stable Cr<sub>2</sub>O<sub>3</sub> passive films and the chemical inertness of chromium carbides.<sup>20</sup> Despite their industrial relevance, a direct electrochemical comparison of WC–Co and Cr<sub>3</sub>C<sub>2</sub> coatings in highly acidic conditions—especially using mechanistic techniques like electrochemical impedance spectroscopy (EIS)—is lacking. Most prior studies examine these materials in isolation or under neutral pH conditions, leaving a gap in understanding how acidic exposure influences their interfacial behavior and long-term degradation.

corrosion protection strategies. As sustainability and lifecycle costs gain prominence, the deployment of such advanced coatings can significantly extend the service life of critical components, reduce maintenance frequency, and improve the overall efficiency of industrial systems. Moreover, scaling the coating processes for complex geometries and additive manufacturing components could unlock new frontiers in high-performance surface engineering.

### LIMITATIONS

While the current investigation provides valuable insights into the corrosion performance of WC-Co and Cr<sub>3</sub>C<sub>2</sub> coatings on DSS 2205 in chloride-rich environments, several limitations must be acknowledged. First, the electrochemical tests were conducted under controlled laboratory conditions using a 3.5 wt.% NaCl solution, which may not fully replicate the complexities of real-world service environments involving fluctuating pH, temperature, flow dynamics, and mechanical loading. Additionally, the study focused primarily on the initial corrosion behavior; long-term degradation mechanisms, such as coating delamination, under-film corrosion, or erosion–corrosion synergy, were not explored.

The use of thermally sprayed coatings inherently introduces microstructural defects such as porosity and micro-cracks, which may vary with deposition parameters. However, this study did not comprehensively investigate the influence of these microstructural features or quantify their role in localized corrosion initiation. Furthermore, only two coating systems were examined. Other emerging coatings (e.g., nanocomposites, multilayered structures, or hybrid systems) may offer improved performance but were beyond the scope of this work. Finally, while SEM and EDX provided qualitative and semi-quantitative insights into surface degradation and elemental distribution, advanced characterization techniques such as XPS, TEM, or EIS could provide a deeper mechanistic understanding and should be considered in future work.

### CONCLUSION

- This study presents a direct, side-by-side electrochemical benchmarking of WC-Co and Cr<sub>3</sub>C<sub>2</sub> coatings on steel substrates in 3.5 wt.% NaCl, offering valuable comparative insights within a controlled, application-relevant environment that is not extensively covered in existing literature.
- The Cr<sub>3</sub>C<sub>2</sub> coating exhibited a 30% reduction in corrosion rate compared to uncoated steel, affirming its superior passive film stability and dense microstructure, making it a robust candidate for aggressive environments.
- Unlike fragmented past assessments, this work quantifies coating performance under controlled

industrial-like conditions, enabling data-driven coating selection for sectors such as chemical reactors, acid pickling plants, and offshore structures.

- The findings set the foundation for next-generation corrosion-resistant systems, promoting cost-effective lifecycle design and reduced maintenance needs in infrastructure exposed to aggressive media.

### DATA AVAILABILITY

Data supporting the findings of the study are available within the article.

### CONFLICT OF INTEREST

The authors declare no competing interests.

### ETHICAL APPROVAL

We comply with ethical standards. We provide our consent to take part.

### CONSENT TO PARTICIPATE/PUBLICATION

The authors provide consent to participate/publication.

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