International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 10 | Oct 2025 www.irjet.net p-ISSN: 2395-0072

Recent Developments in Surface Coating for Corrosion Protection: A Review

A. Athulya

Department of Metallurgical and Materials Engineering
National Institute of Technology, Srinagar

---***---

Abstract - *Corrosion is a major industrial issue causing severe material degradation and economic losses. Surface coatings serve as an efficient and economical approach to mitigate corrosion by providing a barrier between the metal surface and its environment. This paper reviews recent advancements in coating technologies such as nanocomposite coatings, sol–gel coatings, plasma-assisted processes, and environmentally friendly alterna- tives to traditional chromium-based systems. It also highlights emerging smart and self-healing coatings and the integration of AI-assisted monitoring for sustainable corrosion control.*

***Key* Words:** Corrosion, Surface Coating, Nanocomposite, Sol–gel, Self-healing, Eco-friendly coatings, AI monitoring

INTRODUCTION:

Corrosion is an electrochemical process leading to the degradation of metals in the presence of moisture, oxygen, or aggressive environments. Globally, corrosion results in massive economic losses and safety risks in industries such as automotive, aerospace, marine, and construction. Surface coatings are one of the most effective and economical means of corrosion protection due to their versatility and adaptabil- ity. Traditional coatings like zinc, nickel, and chromium are effective but face challenges in environmental compliance and long-term performance. Recent developments have focused on nanocomposite, sol–gel, plasma, and smart coatings that enhance corrosion resistance and sustainability

TYPES OF COATING TECHNIQUES

A. Electrochemical and Electroplating Coatings

Electroplating is one of the oldest and most reliable coat- ing techniques, used for depositing metal coatings such as zinc, nickel, and chromium. Recent innovations like pulse electrodeposition and alloy coatings (e.g., Zn–Ni, Ni–W) have shown improved corrosion resistance and hardness. Nanoparti- cle incorporation (SiO_2, Al_2O_3, TiO_2) leads to nanocomposite coatings with superior wear and corrosion resistance [1].

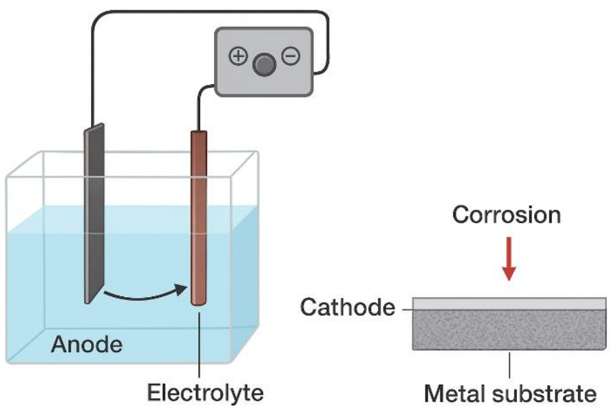

Fig. 1: Electroplating process setup.

B. Conversion Coatings

Conversion coatings react chemically with the metal sub- strate to form a protective film. Chromium-free conversion coatings based on zirconium, titanium, or rare earth elements have emerged as environmentally friendly alternatives [2].

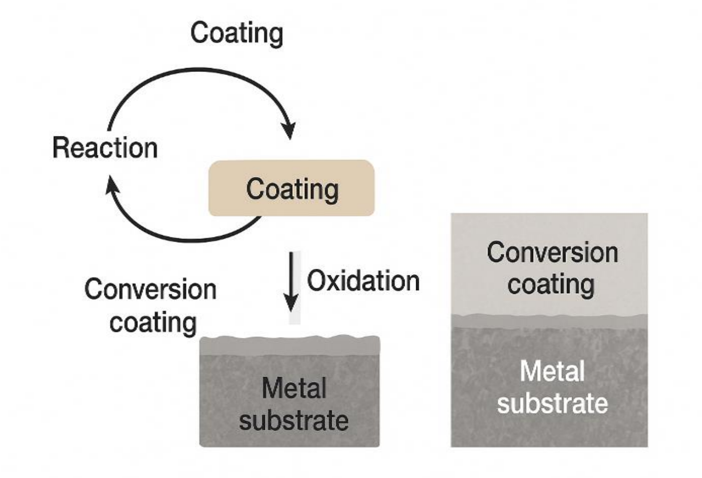

Fig. 2: Schematic of conversion coating formation

C. Physical and Chemical Vapor Deposition (PVD/CVD)

PVD and CVD techniques produce hard, dense coatings such as TiN, CrN, and AlTiN. Plasma-assisted versions en- hance coating uniformity and adhesion. These are widely used in aerospace and tooling applications due to their high durability [3].

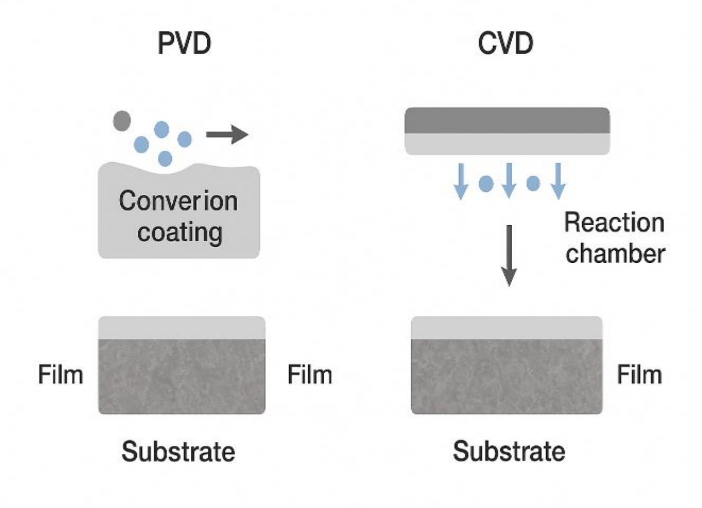

Fig. 3: Comparison of PVD and CVD coating processes

D. Sol–Gel and Nanocomposite Coatings:

Sol–gel coatings are eco-friendly and allow incorporation of nanoparticles such as SiO_2, TiO_2, and graphene oxide. These coatings provide excellent corrosion resistance and are particularly suitable for lightweight alloys like aluminum and magnesium [4]

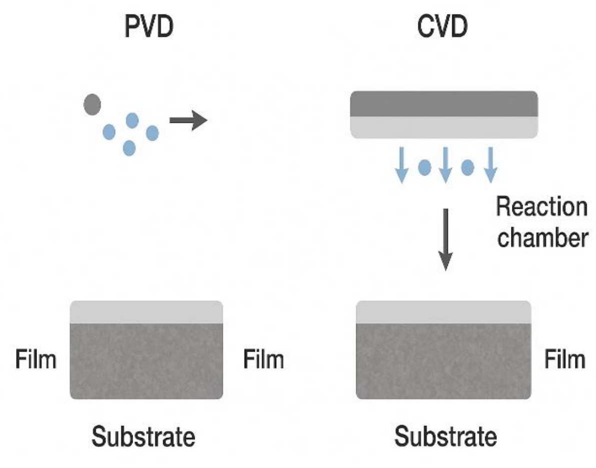

Fig. 4: Sol–gel coating mechanism.

E. Polymer and Hybrid Coatings

Polymer-based coatings like epoxy, polyurethane, and polyaniline act as effective barriers. Modern research focuses on self-healing coatings containing microcapsules that au- tonomously release inhibitors or monomers to repair damaged regions [5].

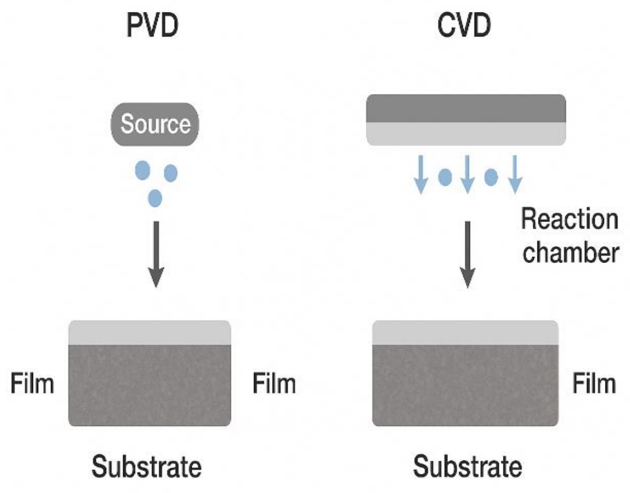

Fig. 5: Self-healing coating mechanism

I. Mechanism of Corrosion Protection

Coatings protect metal substrates through multiple mecha- nisms including barrier protection, sacrificial protection, pas- sivation, and self-healing. Barrier coatings limit access of cor- rosive species like oxygen and water. Sacrificial coatings (e.g., zinc on steel) corrode preferentially to protect the base metal. Chemical passivation layers form stable oxides that prevent further corrosion, while self-healing coatings release inhibitors to repair defects. Recent developments include AI-assisted monitoring systems capable of detecting coating degradation in real-time using embedded sensors [6].

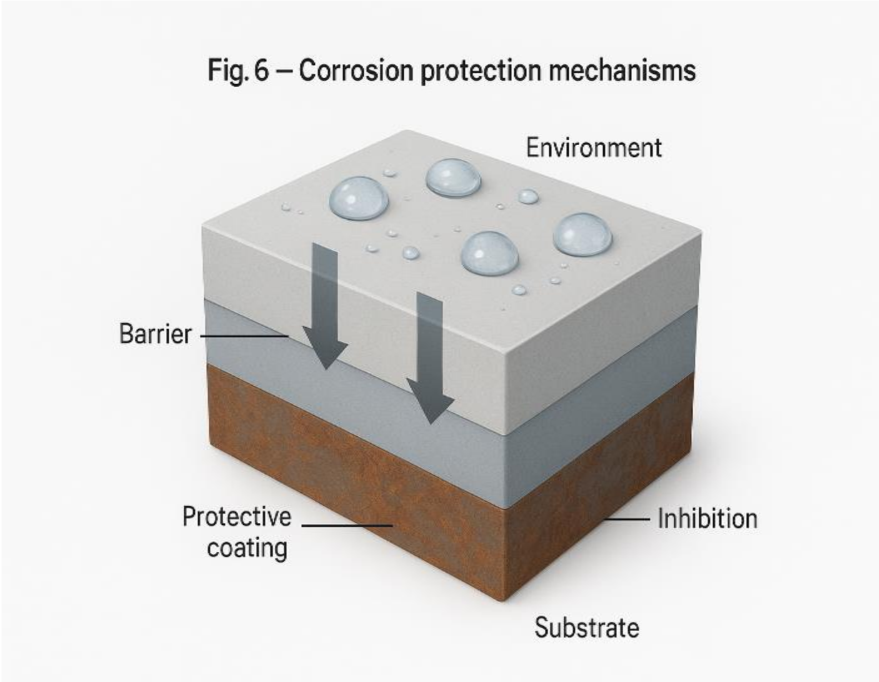

Fig. 6: Mechanisms of corrosion protection (AI-assisted rendering)

Table -1: Comparison of Major Coating Techniquess for Corrosion Protection

Technique	**Characteristics**
Electroplating	Economical and adherent, but may involve toxic chemicals.
Conversion Coating	Environmentally safe but limited thickness.
PVD/CVD	Hard, dense coatings but expensive and high-temperature processes.
Sol–Gel	Eco-friendly and adaptable, though less wear- resistant.
Polymer/Hybrid	Flexible and self-healing but prone to UV degradation.

Recent research emphasizes eco-friendly, nanostructured, and smart coatings. Graphene-based barriers, plasma-assisted depositions, and hybrid sol–gel systems are key trends. Fu- ture directions include bio-based polymer coatings, AI-driven corrosion monitoring, and self-sensing coatings capable of adaptive response to environmental conditions. The integration of data-driven predictive models and sustainable materials is expected to redefine corrosion protection technologies by 2030 [7].

CONCLUSIONS

Surface coatings continue to play a vital role in corrosion control. Recent progress in nanostructured, hybrid, and self-healing coatings has improved both performance and sustain- ability. Future advancements will likely focus on smart, self-sensing, and environmentally safe systems integrated with AI- based diagnostics for long-term reliability.

REFERENCES

[1] S. Ramesh et al., “Recent progress in nanocomposite coatings for corrosion protection,” Surface & Coatings Technology, vol. 438, 2022.

[2] L. Zhang et al., “Chromium-free conversion coatings for aluminum alloys: A review,” Progress in Organic Coatings, vol. 182, 2023.

[3] N. Gupta and A. Sharma, "Recent developments in graphene-based coatings for corrosion resistance," Journal of Alloys and Compounds, vol. 986, 2024.

[4] R. Singh and P. Kumar, "Sol–gel coatings: A sustainable approach for corrosion protection," Journal of Materials Research and Technology, vol. 15, pp. 100–115, 2021.

[5] Y. Chen et al., "Self-healing polymer coatings for anti-corrosion appli- cations," Corrosion Science, vol. 174, 2020.

[6] T. Wang et al., "AI-driven monitoring of coating degradation: A new paradigm in corrosion control," Coatings, vol. 15, no. 2, 2024.

[7] K. Patel and J. Verma, "Smart coatings and predictive corrosion preven- tion," Materials Today: Proceedings, vol. 83, 2025.