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Review Article

A Comprehensive Review of the Use of Epoxy–Acrylic Hybrid Resins in Anti-Corrosion Paints

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Abstract: Epoxy–acrylic hybrid resins have emerged as advanced binder systems for anticorrosion coatings, combining the superior adhesion, chemical resistance, and barrier properties of epoxy with the flexibility, weatherability, and UV resistance of acrylic polymers. Traditional epoxy coatings often suffer from brittleness and environmental degradation, whereas acrylic coatings alone provide limited corrosion protection. Hybridization offers a synergistic approach to overcome these limitations. This review presents a comprehensive overview of synthesis and hybridization strategies, including interpenetrating polymer network (IPNs) copolymerization, emulsion polymerization, core–shell structure, and grafting approaches. Mechanisms contributing to enhance corrosion performance, such as improving barrier properties, mechanical flexibility, adhesion, and environmental durability, are discussed in detail. Performance evaluations from standardized corrosion tests, including salt spray, electrochemical impedance spectroscopy, and immersion studies, demonstrate the effectiveness of hybrid coatings compared with single-component systems. Emerging trends in waterborne and low volatile organic compounds (VOC) formulations, nanocomposite hybrids, and smart coatings with self-healing or responsive properties. Challenges such as phase compatibility, processing complexity, and long-term durability have also been discussed. Overall, epoxy–acrylic hybrid resins represent a promising approach for developing durable, high-performance, sustainable, and environmentally compliant anticorrosion coatings.

Keywords: Anticorrosion coatings; Barrier properties; Epoxy–acrylic hybrid; Nanocomposites; Waterborne resins

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1. Introduction

Corrosion of metallic materials represents a major economic and structural challenge worldwide, affecting industries such as marine engineering (Oliveira et al., 2026; Shojaei et al., 2025), infrastructure, automotive (Priyadharshini & Xavier, 2026), and the energy sector (Kania, 2023; Manu et al., 2025). Protective coatings prevent corrosion by forming a barrier that inhibits contact between the metal surface and corrosive species (Çetinkaya et al., 2025; Liu, 2025; Saikia et al., 2025; Zade & Patil, 2024). Exposure of metals to aggressive environments containing moisture, oxygen, salts, and pollutants leads to electrochemical degradation, resulting in structural failure, economic losses, and safety concerns (Aslam et al., 2025; Muthukumaran, 2026; Srikanth, 2026; Zade & Patil, 2024). Among the various corrosion mitigation strategies, organic protective coatings are the most widely adopted because of their cost-effectiveness, ease of application, and ability to provide long-term protection by forming a physical and chemical barrier between the metal substrate and the surrounding environment (Aljibori et al., 2024; Subbiah et al., 2025). Anticorrosion paints serve as the first line of defense by establishing a protective barrier between metal substrates and aggressive environments (e.g., chloride ions, moisture, and oxygen) (Liu, 2025; Saikia et al., 2025; Zade & Patil, 2024).

Epoxy resins are among the most extensively used binders in anticorrosion paints owing to their excellent adhesion to metallic substrates, high mechanical strength, excellent barrier properties, and superior resistance to chemicals and solvents (Abiodun et al., 2025; Hao et al., 2025; Mohanty et al., 2025; Negim et al., 2025; Wang et al., 2025). The physical and chemical characteristics of epoxy resins are relevant to corrosion protection, including high crosslink density (Anwar & Li, 2024; Kotb et al., 2023), excellent adhesion to metallic substrates, superior chemical (Wang et al., 2025), solvent resistance, and strong barrier properties that inhibit the penetration of water, oxygen, and aggressive ions. The densely crosslinked epoxy network effectively limits the penetration of corrosive species, making epoxy coatings suitable for harsh environments (Wang et al., 2025; Zaghloul et al., 2023). However, despite these advantages, conventional epoxy coatings suffer from inherent drawbacks, such as brittleness, poor flexibility, limited resistance to ultraviolet (UV) radiation, and susceptibility to cracking under thermal or mechanical stress (Anwar & Li, 2024; Liu, 2025; Vignesh et al., 2026). These deficiencies can compromise coating integrity over time, leading to premature corrosion failure (Vignesh et al., 2026).

In contrast, acrylic resins are well known for their good flexibility, weatherability, UV stability, and ability to retain esthetic properties during long-term outdoor exposure (Aalto-Korte, 2019; Kim et al., 2025; Muradova et al., 2023; Valeriia, 2025). The advantages of acrylic resins include flexibility and toughness, UV resistance, weatherability, environmental stability, and resistance to yellowing and surface degradation during outdoor exposure (Gawali & Jain, 2026; Pojnar et al., 2024; Procopio, 2020). Acrylic coatings exhibit excellent resistance to yellowing, chalking, and environmental aging (Pozo-Antonio et al., 2023). Nevertheless, when used alone, acrylic systems generally provide weaker corrosion protection primarily because of their lower crosslink density and inferior barrier properties compared with those of epoxy resins. Acrylic coatings are often inadequate for applications requiring high corrosion resistance in aggressive environments (Guo et al., 2025; Im et al., 2024).

Significant research efforts have been devoted to the development of epoxy–acrylic hybrid resins (Guo et al., 2025) to overcome the individual limitations of epoxy and acrylic systems, which combine the complementary properties of both polymers within a single coating matrix (Flosbach & Fugier, 2010). Epoxy–acrylic hybrid resins combine the advantages of both systems, producing coatings that exhibit strong adhesion, mechanical flexibility, chemical resistance, barrier efficiency, UV resistance, and enhanced durability under environmental stress (Abd-Elnaiem et al., 2022; Shoily et al., 2025; Tulegenkyzy et al., 2024; Xia et al., 2025). The hybridization of epoxy–acrylic resin enhances coating performance by reducing epoxy brittleness, optimizing crosslink density, stress distribution, and combining barrier protection with weather resistance (Rau et al., 2012). Such hybrid systems can be designed through interpenetrating polymer networks (IPNs), copolymerization, emulsion blending, grafting, or core–shell architectures (e.g., epoxy core/acrylic shell), allowing precise control over morphology, compatibility, crosslink density, and coating performance characteristics (Eyann et al., 2024).

The corrosion protection mechanisms of epoxy resins, acrylic resins, and epoxy–acrylic hybrids, including physical barrier protection, adhesion-mediated corrosion inhibition, crack formation suppression, reduced permeability and defect density, and improved long-term coating stability, are now clearly introduced.

Recently, epoxy–acrylic hybrid coatings have gained increasing attention, particularly in the context of being waterborne and enhancing the service life of protective coatings and low-VOC formulations, driven by stricter environmental regulations and sustainability requirements (Procopio, 2020; Tulegenkyzy et al., 2024). Advances in polymer chemistry, emulsion technology, and nanocomposite design have further expanded the potential of these hybrid systems, enabling improved corrosion resistance, mechanical performance, and durability under challenging service conditions (Tulegenkyzy et al., 2025; Xiao et al., 2025; Yadav et al., 2024).

This review primarily examines studies on epoxy–acrylic hybrid resins used in anticorrosion coatings, covering synthesis methods, hybridization techniques, corrosion-protection mechanisms, coating performance, and sustainability. The selected publications were systematically evaluated and categorized according to these key themes to provide a comprehensive overview of recent advances, existing challenges, and future research directions in this field.

This review provides an in-depth look at the use of epoxy–acrylic hybrid resins in anti-corrosion paints. The discussion focuses on hybridization strategies, fundamental mechanisms responsible for enhancing coating performance, and corrosion resistance evaluation using standardized testing methods. The discussion also highlights sustainable approaches, such as waterborne formulations and low-VOC coatings, to guide researchers and industry practitioners in the development of high-performance, environmentally compliant anticorrosion paints. In addition, current challenges and future research directions are highlighted to guide the development of next-generation hybrid coatings with enhanced protection and environmental compatibility.

2. Hybridization Strategies

The performance of epoxy–acrylic hybrid resins in anticorrosion paints is strongly influenced by the method used to combine the epoxy and acrylic components (del Castillo et al., 2025; Zhu et al., 2026). Effective hybridization strategies are required to ensure compatibility, uniform morphology, and synergistic properties because these polymers differ in polarity, curing behavior, and molecular architecture (Guo et al., 2025). Hybridization strategies play a crucial role in determining the structural integrity, barrier efficiency, durability, and synergistic properties of epoxy–acrylic anticorrosion coatings (Faccini et al., 2021; Kumar et al., 2023a). Among the various approaches, chemically bonded hybrids and core–shell architectures offer superior performance due to improved compatibility and controlled morphology (Chen et al., 2016; Eyann et al., 2024).), while emulsion polymerization supports the development of environmentally friendly coating systems (Adnan et al., 2025; del Castillo et al., 2025; Pieters & Mekonnen, 2024). The continued refinement of hybridization techniques is essential for optimizing coating performance and meeting future industrial and environmental demands (Kardar & Amini, 2026; Samoilenko et al., 2024).

Several approaches have been developed to hybridize epoxy and acrylic systems to influence phase compatibility, crosslink density, and microstructural uniformity, each offering distinct advantages in terms of structure control, processing, and coating performance depending on the desired structure and final application:

2.1 Physical Blending and IPNs

One of the earliest strategies involves the physical blending of epoxy and acrylic resins, followed by curing to form interpenetrating polymer networks (IPNs) (Ma et al., 2022; Zhou et al., 2025a). In this approach, the epoxy and acrylic networks are independently crosslinked but coexist within the same matrix without covalent bonding (Ma et al., 2022). IPNs improve toughness and flexibility while maintaining the epoxy's strong barrier properties (Gong et al., 2024; Huang et al., 2025; Jurinovs et al., 2026). However, if the compatibility is insufficient, phase separation can occur, leading to heterogeneous morphology and reduced corrosion protection. Therefore, careful control of resin ratios and curing conditions is essential (Makhmetova et al., 2023; Tu et al., 2024).

The proper combination and IPNs enhances mechanical properties that are difficult to achieve solely by the individual polymer components. IPNs exhibit varying degrees of phase separation, depending on the compatibility of the component polymers, but the mechanical properties of the IPNs blends can be much better than the constituent polymers (Cardona et al., 2016). In recent years it has been recognized that the formation of IPNs in thermosets results in improved properties, particularly in toughness. Identified conditions for IPNs formation with thermoset resins are that the curing reactions of their components do not interfere with each other and that their relative amount is proportionally balanced with a phase ratio close or equal to 1:1. IPNs -structured thermosets with Epoxy (EP) resins have been synthesized by the simultaneous reaction with in-situ formed polyurethanes (PU) (Kausar, 2019); unsaturated polyester (UP) resins and PU; aliphatic acrylates, and with vinyl ester (VE). Most of the cited studies were focused on improving viscoelastic and mechanical propertie (Cardona et al., 2016).

(Rau et al., 2012) created a hybrid acrylic polyol–epoxy polyol coating system treated with an aliphatic polyisocyanate via adhesion and electrochemical impedance spectroscopy (EIS) techniques to protect mild steel substrates from corrosion. Polyisocyanate improved the adherence of the coating to the metal surface by acting as a coupling and crosslinking agent. EIS and accelerated exposure experiments were used to assess the different acrylic/epoxy blending ratios and characterize the mechanical and corrosion-resistant capabilities of the resulting coatings. The findings showed that the addition of epoxy polyol to the acrylic matrix enhanced coating durability and protective effectiveness by creating a strongly crosslinked network. Among the nine formulations examined, one optimized hybrid composition showed the best combination of adhesion, mechanical integrity, and long-term corrosion resistance, suggesting that acrylic–epoxy polyol hybridization is a successful method for creating long-lasting protective coatings for steel substrates.

2.2 Copolymerization Using Functional Acrylic Monomers

Copolymerization strategies employ functional acrylic monomers, such as glycidyl methacrylate or hydroxyethyl methacrylate, which can chemically interact with epoxy groups (Makhmetova et al., 2023; Zhou et al., 2025b). These monomers enable the formation of covalent bonds between epoxy and acrylic segments, resulting in improved interfacial adhesion and more homogeneous hybrid structures (Aronovich & Boinovich, 2021). Chemically bonded hybrids typically exhibit enhanced mechanical integrity, reduced microvoid formation, and improved resistance to permeation by corrosive species (Kumar et al., 2023a).

Zhou et al. (2025a) described the preparation of a novel epoxy acrylate hybrid resin viscosity-reducing agent via a straightforward synthesis method by incorporating varying amounts of glycidyl methacrylate (GMA) monomers. Mechanism of the epoxy acrylate viscosity reducer in the synthesis process (Figure 1a). The findings revealed an increase in the thermal stability of the resin due to GMA modification and a decrease in the viscosity of the heavy oil. The average particle size and Zeta potential of the obtained hybrid resin increased from 187 nm, and −40 mV, respectively, to 15 wt.% GMA. The thermal degradation temperature of W15 increased significantly from 450 °C to 517 °C, indicating improved thermal stability. The incorporation of W15 viscosity-reducing epoxy acrylate (GMA-modified) provides an effective viscosity reduction capability for heavy oil (Figure 1b). The addition of 8 wt. % W15 epoxy acrylate led to an approximately 89% decrease in heavy-oil viscosity (Figure 1c), highlighting its strong viscosity-reducing performance (Figure 1d). Overall, this work presents the successful synthesis of a novel epoxy acrylate-based viscosity reducer prepared through a straightforward synthetic route, which is characterized by high stability, economic feasibility, and outstanding viscosity-reduction efficiency.

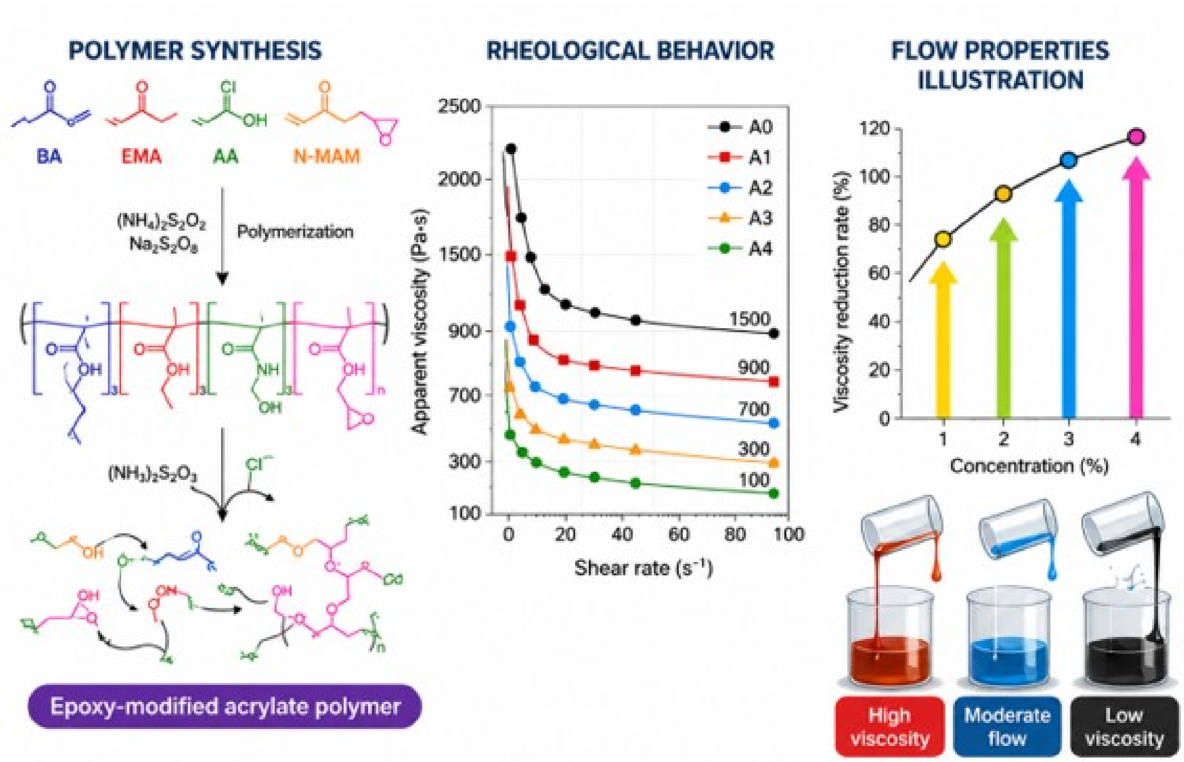

Figure 1 Schematic of the synthesis pathway for the epoxy acrylate hybrid resin. Rheological behavior of the viscosity-reducing agent of W15 epoxy acrylate hybrid resin, showing the variation in viscosity with shear rate at different concentrations. Viscosity reduction efficiency of heavy oil treated with different concentrations of the W15 viscosity-reducing agent: 2 wt.% (A1), 4 wt.% (A2), 6 wt.% (A3), and 8 wt.% (A4). (d) Photographic comparison demonstrates the viscosity-reducing agent's effect on the heavy oil's flowability.

Another study by Tulegenkyzy et al. (2025) mentioned the preparation terpolymer from glycidyl methacrylate (GMA), butyl acrylate (BuA), and methyl methacrylate (MMA) via free radical solution polymerization to lower the high viscosity of epoxy resin with improved properties when combined with an amine-based hardener at ratios of 1:1, 1:0.5, and 1:0.3 obtained for diverse applications. The obtained terpolymer improved viscosity, mechanical properties, adhesion, corrosion and solvent resistance at higher MMA Content. The best mechanical properties were attained with a 70:10:20 monomer ratio (ERD1) in epoxy hybrids at a 1:0.5 hardener ratio. The obtained terpolymer enhanced chemical and solvent resistance of epoxy hybrids. According to the findings the valuable insights for enhancing solvent formulations in the coatings industry, enabling the development of solvent-free coatings with superior mechanical performance and a lower environmental footprint.

2.3 Grafting and Chemical Modification

Grafting techniques involve the attachment of acrylic chains onto epoxy backbones or the modification of epoxy resins with acrylic functional groups (Aronovich & Boinovich, 2021; Kumar et al., 2023a; Liu et al., 2023). Compatibilizers and coupling agents (e.g., silanes) are also used to enhance the interfacial adhesion between the two polymer phases, resulting in more homogeneous coatings (Aziz et al., 2021). These chemical modifications improve compatibility and promote uniform dispersion of both components within the coating matrix (Nasirzadeh et al., 2025). Grafted hybrids often exhibit enhanced mechanical performance, improved adhesion, and superior corrosion resistance due to the formation of a tightly integrated polymer network (Kumar et al., 2023a).

By grafting high-molecular-weight epoxy resin with methacrylic acid, styrene, and butyl acrylate while maintaining the epoxy functional groups, Liu et al. (2023) created a stable self-emulsifying waterborne epoxy–acrylic emulsion. The grafted epoxy–acrylic copolymers produced stable aqueous emulsions with an average particle size of approximately 160 nm and outstanding long-term storage stability for more than a year. They also exhibited better glass transition temperatures. Additionally, the emulsions exhibited exceptional mechanical, freeze-thaw, and dilution stability. After curing at 150°C for 1 h, the coatings demonstrated exceptional mechanical qualities, such as 5H pencil hardness, grade 1 adhesion, and 1 mm flexibility. They also demonstrated remarkable chemical resistance to water (>60 days), salt water (>30 days), acids (>10 days), and alkalis (>5 days). These results indicate that graft-modified waterborne epoxy–acrylic emulsions are a viable method for creating eco-friendly coatings with enhanced chemical resistance, stability, and durability.

2.4 Emulsion Polymerization and Hybrid Waterborne Systems

Emulsion polymerization is widely used to produce waterborne epoxy–acrylic hybrid resins, addressing environmental concerns related to volatile organic compound (VOC) emissions (Sinha & Dey, 2025; Xiao et al., 2025). In this method, epoxy resins are emulsified in water and combined with acrylic monomers polymerized in situ under surfactant/stabilizer systems to form well-dispersed hybrid particles or stable hybrid latex particles (Chen et al., 2023a; Yao et al., 2017). This approach improves environmental compliance by reducing the solvent content. The resulting coatings demonstrate good film-forming ability, improved flexibility, and competitive corrosion resistance compared with those of solvent-based systems (Yao et al., 2017). Emulsion-based hybrids are particularly attractive for industrial applications that require environmentally friendly formulations (Chen et al., 2023b; Fu & Wang, 2025; Guo et al., 2025; Liu et al., 2023).

Guo et al. (2025) created epoxy–acrylic hybrid resins via emulsion polymerization by using Triton X-405 (octylphenol ethoxylate) as surfactant. a waterborne epoxy curing agent was incorporated to form cured coatings. The obtained epoxy–acrylic hybrid displays significant improvements in physical properties. The obtained epoxy– styrene-acrylate hybrid enhances both the physical and anti-corrosion properties of the coating. The obtained epoxy–acrylic hybrid enhanced the mechanical properties of the cured coating with adhesion reaches 1.21 MPa, the hardness reaches H, flexibility is 0.5 mm and exhibited latex particle size distribution is the narrowest at the epoxy resin content reaches 15% of the acrylic resin. The obtained epoxy–acrylic hybrid enhanced the thermodynamic properties are compared to those of pure acrylic resin and enhanced the anti-corrosion with a corrosion current density (I_{corr}) of 6.9506×10^{-7} A/cm^2 and a corrosion potential (E_{corr}) of -0.2291 V, demonstrating excellent corrosion resistance.

Chen et al. (2023b) created self-cross-linked epoxy-acrylate hybrid with three-layer core–shell structure.via emulsion copolymerization, The stability of the composite latex was characterized by zeta potential (ZP), particle size (PS), and storage stability. And the corrosion resistance of the composite latex films was analyzed by electrochemi cal AC impedance spectroscopy and salt spray tests. The obtained epoxy-acrylate hybrid enhances the thermal stability and adhesion strength of the film but also hinders the penetration of corrosive media into the film, thereby providing effective corrosion protection. The obtained epoxy-acrylate hybrid with best stability and corrosion resistance was obtained when the modified epoxy resin in the core layer was 10 wt% and MAA in the shell layer was 1wt. % of the total monomer weight. This film exhibited a Rct value $1.49 \times 10^7\ \Omega\ \text{cm}^2$ after being soaked in 3.5wt. % NaCl for 1 day and dropped by one order of magnitude after 7 days. The results reveal that self-cross-linking reaction occurs between epoxy groups in the core layer with carboxyl groups in the shell layer during film formation. The outstanding stability as well as corrosion resistance is attributable to the cross-linking reticulation structure. It is a new strategy for improving the corrosion resistance of the film through emulsion's intrinsic properties.

Anathor study (Zhang et al., 2021) mentioned the fabriction of stable and self-crosslinking waterborne epoxy-styrene-acrylate composite via multi-stage seed emulsion polymerization. The stable emulsion copolymerization that occurred between the modified epoxy resin and acrylate monomer, the presence of carboxyl groups in the obtained latex was evidenced, while the epoxide groups were partially retained. The anticorrosion resistance and stability of the multilayer composite latex with the intermediate layer are better than that of the conventional core-shell latex. The outstanding stability and corrosion resistance is attributed to the multilayer core-shell structure. The TOPEM-DSC approach can accurately determine the thickness of the intermediate layer in the multilayer core-shell particles and is a new strategy for characterizing the core-shell structure of polymer particles with a similar monomer composition.

Chen et al. (2023a) reported the synthesis of waterborne epoxy–acrylic hybrid resins using an emulsion polymerization approach. In this system, ethanolamine (ETA) was used to modify the epoxy component, providing a basic environment that facilitates the dissociation of carboxylic acid groups present in the acrylic segments in aqueous media. This process enhances the emulsion's electrostatic stabilization (Figure 2). The resulting hybrid resin particles were smaller than 300 nm, and the prepared emulsions maintained excellent stability for more than nine months of storage. The synthesized resins also exhibited favorable thermal properties, with a glass transition temperature (T_g) of approximately 104.6 °C and a thermal degradation temperature (T_d) of 330.4 °C. In addition, the coatings showed strong corrosion resistance, with less than 5% rust formation observed on the steel substrates after a 5-h salt spray exposure test.

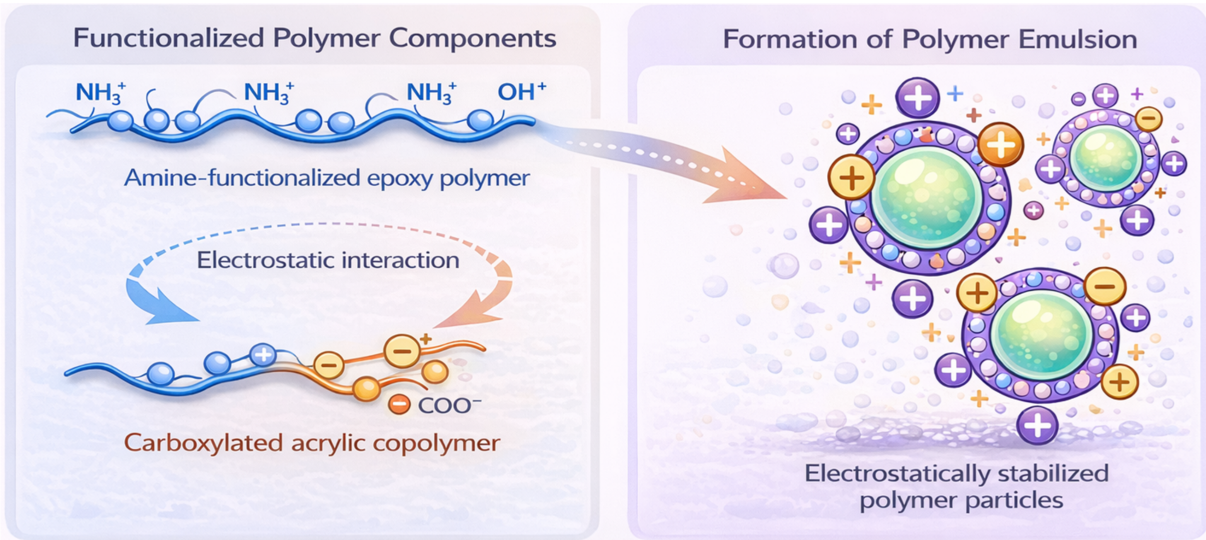

Figure 2 Schematic illustration of electrostatic interactions between amine-functionalized epoxy polymers and carboxylated acrylic copolymers leading to the formation of stable polymer emulsions.

By dispersing epoxy resin (DER-331) in water using Triton X-405 surfactant and a phase inversion technique, Guo et al. (2025) created a waterborne epoxy–acrylic hybrid coating. This was then hybridized using a styrene–acrylic emulsion. Because a thick crosslinked network was formed after curing, the addition of epoxy resin greatly enhanced the coating's performance. The ideal formulation was found to have the smallest particle size distribution and the best overall characteristics with an epoxy concentration of 15 wt.% in relation to acrylic resin. With a corrosion current density of 6.95×10^{-2} A cm^{-2} and a corrosion potential of -0.2291 V. Moreover, the cured coating demonstrated increased mechanical performance (hardness H, flexibility 0.5 mm, and adhesion strength 1.21 MPa) and improved thermal stability. Aqueous epoxy–acrylic hybridization is a successful method for creating eco-friendly coatings with superior mechanical and anticorrosive qualities.

2.5 Compatibilizers and Coupling Agents

Compatibilizers, such as silane coupling agents, reactive surfactants, or block copolymers, are frequently employed to enhance the interfacial interaction between the epoxy and acrylic phases (Aziz et al., 2021). These additives reduce interfacial tension, suppress phase separation, and promote uniform morphology. Improved compatibility directly contributes to improved barrier properties and long-term corrosion protection (Kausar, 2019; Wang et al., 2014, 2024).

The epoxy acrylate latexes and silane coupling agent γ-methacryloxypropyltrimethoxysilane (KH-570) modified epoxy acrylate latexes via facile semi-continuous emulsion polymerization. It is confirmed that the acrylate monomers indeed graft onto the molecular chain of E-51 (Bednarczyk et al., 2021; Ercan et al., 2025). The obtained epoxy acrylate emulsion of 80–100 nm particle size with a narrow distribution was obtained. The latex films retain resistance to satisfactory water, acid, alkali, and alcohol while maintaining good thermal stability, adhesion force, and flexibility (Xia et al., 2025; Zhu et al., 2018). The importing of KH-570 could reinforce the spatial structure and cross-linking density and then improve the tensile strength of the latex films properly while keeping other performances well. This study provides a facile pathway for the optimized performance of epoxy acrylate latexes, and represents a tendency for environmental protection (Al-Maharma et al., 2025; Cheaburu-Yilmaz et al., 2022; Jiao et al., 2020; Xie et al., 2021; Zheng et al., 2020)

2.6 Core–Shell Hybrid Structures

Advanced hybridization techniques involve the formation of core–shell structures, where either the epoxy or acrylic component forms the core and the other constitutes the shell. This architecture allows precise control over surface chemistry, particle stability, phase compatibility, and curing behavior and facilitates improved coating formulation dispersion.

For example, an epoxy core with an acrylic shell can provide strong adhesion and barrier properties while improving the coating surface's flexibility and weather resistance. In waterborne coatings, core–shell hybrids are particularly effective in enhancing dispersion uniformity and reducing phase separation (Deng et al., 2025; Pozo-Antonio et al., 2023).

Gharieh et al. (2021) investigated the preparation of acrylic silica nanoparticle/epoxy hybrid systems using Pickering emulsion polymerization to enhance the mechanical performance of epoxy resins (Figure 3). Hybrid particles consisting of an epoxy core and an acrylic shell were synthesized in this approach, which improved the toughness, tensile strength, and elastic modulus of the epoxy matrix. The incorporation of 7 wt.% hybrid resin resulted in a significant increase in mechanical properties, increasing fracture toughness by approximately eight times, fracturing energy by nearly fifty times, and tensile strength by approximately 38%. The improved performance was attributed to several toughening mechanisms, including crack pinning and deflection, as well as debonding of the hybrid particles from the epoxy matrix followed by plastic void growth.

As a result of a review of these studies, it is evident that chemically bonded hybrid films have better corrosion resistance because they have better interface compatibility and fewer defects than physically mixed and other types of films. Although physical blending is easy, the phase separation problem exists. The advantages of water-based emulsions are evident; however, they should be optimized to attain a level similar to that of solvent-based films.

Table 1 provides a comprehensive evaluation of the important epoxy-acrylic hybridization methods to compare the reviewed methodologies in detail. These include their respective strengths, weaknesses, effectiveness at corrosion protection, industrial application, and challenges documented by other researchers.

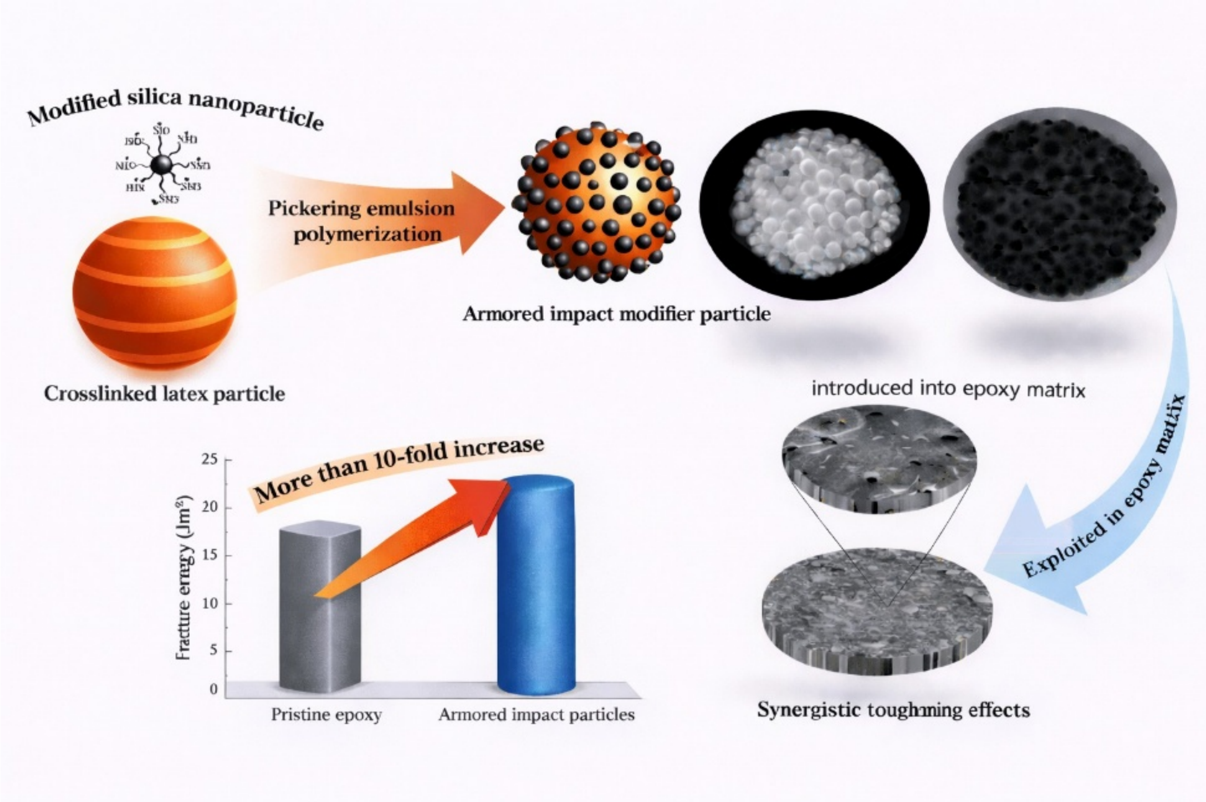

Figure 3 Schematic illustration of the preparation of the core-shell of the acrylic-silica nanoparticle/epoxy hybrid resin

Table 1 Comparison of epoxy–acrylic hybridization strategies for anticorrosion coatings

Strategy	Corrosion Resistance	Compatibility	Industrial Feasibility	Environmental Friendliness	Main Challenge
Physical blending/IPN	Moderate	Moderate	High	Moderate	Phase separation
Copolymerization	High	High	Moderate	Moderate	Complex synthesis
Grafting	High	High	Moderate	Moderate	Multi-step preparation
Emulsion polymerization	Moderate–High	High	High	High	Lower barrier performance
Core–shell structures	Very High	Very High	Moderate	High	Cost and complexity
Compatibilizer-assisted systems	High	High	High	Moderate	Additional formulation cost

Chemical bonding systems, such as copolymers, grafts, and core–shell systems, are generally more effective in terms of corrosion resistance than physical blending techniques because they exhibit good compatibility with phases and defect prevention. Core–shell systems are ideal because they combine dispersion stability with good corrosion resistance. Owing to their eco-friendly nature, emulsion polymers are especially advantageous as green coatings. Nevertheless, the additional complexity and high costs of hybrid systems pose challenges to industrial applications.

The evidence for better performance of chemically bonded hybrid coatings is quite convincing since such findings have been reported in various studies employing electrochemical impedance spectroscopy and salt spray tests. Nevertheless, evidence on their long-term performance and industrial applicability remains inconclusive. Moreover, comparing the results from different hybrid approaches is difficult because of differences in formulations, curing parameters, substrate materials, and corrosion testing techniques.

3. Mechanisms of Performance Enhancement

The superior anticorrosion performance of epoxy–acrylic hybrid resins is attributed to the synergistic interaction between the epoxy and acrylic components at the molecular and microstructural levels. Hybridization not only combines the inherent advantages of each polymer but also introduces new mechanisms that significantly enhance coating durability, barrier efficiency, and mechanical stability under aggressive environments. The enhanced performance of epoxy–acrylic hybrid anticorrosion coatings results from a combination of improved barrier properties, mechanical flexibility, adhesion, environmental durability, and optimized network architecture (Kumar et al., 2023a). These mechanisms work collectively to suppress crack formation, reduce the permeation of corrosive agents, and maintain coating integrity over extended service periods. Moreover, epoxy–acrylic hybrids exhibit improved corrosion protection through several synergistic mechanisms:

3.1 Barrier Protection and Microstructural Integrity

The formation of a dense and compact polymer network is one of the primary mechanisms of corrosion protection in epoxy–acrylic hybrid coatings. The dense crosslinked network derived from epoxy provides a physical barrier against corrosive species (water, oxygen, and salts), fills microvoids, and reduces permeability (Gharieh et al., 2021). Compared with single-component systems, hybrid coatings result in lower water uptake and delayed electrolyte penetration. Hybrid films often show reduced porosity and diffusivity, which slows the ingress of aggressive ions (Guo et al., 2025; Yin et al., 2025). Effective hybridization strategies lead to improved compatibility between the epoxy and acrylic phases, preventing phase separation, or producing homogeneous microstructures with minimal phase separation. A uniform morphology reduces the presence of defects such as pores, voids, and weak interfacial regions that can act as corrosion initiation sites. Therefore, homogeneous hybrid films exhibit superior long-term barrier performance.

Naveed et al. (2026) created halloysite nanotubes (HNTs) loaded into epoxy/epoxy acrylate hybrid via a ring-opening reaction at varying weight ratios of epoxy/epoxy acrylate (75/25, 50/50, and 25/75). Our findings reveal that this unique approach fosters highly interpenetrated polymer networks (IPNs), as evidenced by thermal and viscoelastic behavior. The hybrid epoxy nanocomposite with a 75/25 blend ratio exhibits a superior balance of properties, demonstrating a synergistic enhancement in both thermal and thermomechanical properties compared to the neat epoxy and epoxy acrylate networks. The optimized hybrid epoxy composite exhibits a 147% increase in storage modulus (E') and a 180% increase in loss modulus (E'') over the neat epoxy composite while enhancing thermal stability. This study not only presents HNT-reinforced epoxy/epoxy acrylate as a new family of robust hybrid nanocomposites but also provides a fundamental blueprint for compatibilizing and reinforcing thermoset blends for advanced applications.

3.2 Mechanical Properties and Adhesion Stability

Conventional epoxy coatings are inherently brittle due to their rigid crosslinked structure (Zhang et al., 2025). The incorporation of acrylic chains introduces flexibility, reduces brittleness, improves toughness, reduces microcracks, preserves coating integrity under stress, and promotes elongation at break (Bhat et al., 2024). Increased toughness decreases crack formation under mechanical or thermal stress, preserving barrier integrity over extended service conditions (Jing et al., 2023; Yin et al., 2025). This enhanced flexibility allows the coating to better accommodate thermal expansion, mechanical deformation, and substrate movement without cracking. Because microcracks act as preferential pathways for corrosive species, their suppression plays a critical role in extending coating service life (Zeng et al., 2025). Epoxy–acrylic hybrid resins exhibit improved adhesion to metallic substrates due to the presence of polar functional groups and enhanced stress distribution within the coating matrix (Rau et al., 2012). The epoxy component ensures strong chemical and mechanical bonding to the metal surface, whereas the acrylic domains reduce the internal stresses generated during curing and enhance the interfacial stability (Demiral, 2025). Acrylic domains help distribute mechanical stresses, minimizing delamination and blistering at the substrate–coating interface. This combination minimizes interfacial debonding, blister formation, and delamination, which are common precursors of underfill corrosion.

3.3 Network Architecture and Environmental Durability

Hybrid systems allow precise control over crosslink density by balancing hard epoxy networks and flexible acrylic chains to achieve an optimal crosslink density that minimizes microdefects without sacrificing flexibility (Zhou et al., 2025a). An optimized crosslinked structure improves coating hardness without brittleness and chemical resistance while maintaining sufficient elasticity. Acrylic segments mitigate the adverse effects of excessive crosslinking by reducing brittleness, thereby producing a robust and resilient coating network that provides long-term protection. Acrylic polymers are well known for their resistance to ultraviolet radiation and environmental aging (Gao et al., 2019; Kotnarowska, 2018). Their incorporation into epoxy-based coatings improves resistance to UV-induced degradation, yellowing, and chalking. Acrylic segments provide UV stability, weather resistance, and extended service life (Bernacki et al., 2018; Flosbach & Fugier, 2010; Zhang et al., 2026). The extended coating lifespan and enhanced weatherability help maintain coating integrity and surface protection during prolonged outdoor exposure, indirectly contributing to sustained corrosion resistance.

3.4 Synergistic Interaction with Additives and Fillers

Epoxy–acrylic hybrid matrices provide an excellent platform for incorporating corrosion inhibitors, pigments, and nanofillers (Kumar et al., 2023a). The hybrid network improves filler dispersion and interfacial bonding, enhancing tortuosity within the coating and slowing the transport of corrosive species. Nanofillers and corrosion inhibitors disperse more effectively in hybrid matrices, thereby enhancing barriers and chemical protection. This synergy amplifies both the physical and chemical mechanisms of corrosion protection.

Fang et al. (2025) created TA@Benzotriazole@ Poly (hydroxypropyl acrylate-triethoxyvinylsilane -acrylic acid) (TBP) / polyethylenimide (EP) gels via the free radical polymerization method/ co-precipitation method to modify the protective performance of the coatings. The EIS, salt spray test and adhesion test were used to test the protective performance of the coatings. Following the 181d immersion test, the TBP/EP coatings sustained an impedance value of 2.36×10^7 Ω cm^2. In contrast, the impedance value of the epoxy coatings decreased to 6.86×10^4 Ω cm^2. In comparison to epoxy coatings, the TBP/EP coatings demonstrated a notable enhancement in original adhesion and wet adhesion, with increases of 18.21% and 74.7%, respectively. In the end, the TBP/EP coatings corrosion inhibition functions were innovatively introduced.

4. Performance in Corrosion Tests

Epoxy–acrylic hybrid coatings have been evaluated using standard corrosion assessment techniques, yielding promising results as follows:

4.1 Corrosion assessment methods

Salt spray tests (ASTM B117) revealed that hybrid coatings significantly outperformed pure acrylic coatings and, in many instances, matched or exceeded traditional epoxy coatings in terms of resistance to white rust and red rust progression. The hybrid coatings can significantly reduce corrosion currents and shift corrosion potentials toward more noble values, indicating slower corrosion kinetics on metal substrates. After extended exposure, the hybrid films demonstrate fewer visual defects (del Castillo et al., 2025; Guo et al., 2025). EIS measurements indicate higher impedance values for hybrid coatings compared to neat epoxy or acrylic systems, reflecting improved barrier performance and slower breakdown of protective films under corrosive conditions (Kumar et al., 2023a).

A novel phosphate ester functional monomer, hydroxyethyl methacrylate ethyl phosphate (HEMAPE), was incorporated into a water-borne acrylic–epoxy hybrid resin via free-radical polymerization. The resulting hybrid resin exhibited enhanced dispersion stability in aqueous media, improved mechanical properties, and superior anticorrosion performance. These improvements were attributed to the formation of phosphate chelates within the cured coating, where the HEMAPE functional groups effectively chelated metallic ions generated from corrosion products on the steel substrate. The resulting chelates formed a protective interfacial layer, thereby enhancing coating adhesion and corrosion protection. Owing to these characteristics, the developed hybrid resin shows significant potential for use in environmentally friendly anticorrosion coatings for metal protection (Xiao et al., 2024).

Kumar et al. (2023b) created epoxy–acrylic-PDMS polymeric modified with graphene nanofillers via chemical modification to improve the coatings' corrosion protection performance and hydrophobicity. The obtained hybrid resin exhibited outstanding adhesion to the coating (Figure 4a). WCA values (degrees) for all coating samples with PDMS incorporation (Figure 4b). EIS was employed to evaluate the coatings' corrosion protection performance (Figure 4c). The EIS results of the obtained hybrid resin revealed that the T1, T5, and T7 coating samples containing higher ratios of acrylic resin exhibited pronounced impedance modulus ($|Z|_{0.01\text{Hz}}$) values exceeding 10^{10} Ω cm^2 after 60 days of exposure to the corrosive medium, 3.5 wt.%. % NaCl solution (Figure 4d). The results indicated that both the T1 and T5 coating samples maintained a fully capacitive response even after immersion for 60 days. This behavior demonstrates that these coatings provide effective barrier protection against corrosive media. The T5 coating demonstrated the most favorable performance among the tested samples, indicating its superior corrosion protection capability.

Hybrid coatings typically outperform pure acrylic coatings in aggressive environments (e.g., saline immersion) due to the barrier efficiency of epoxy. Hybrids show minimal blistering and lower corrosion current densities in long-term immersion in saline solutions, demonstrating stable protective behavior even in aqueous environments (Guo et al., 2025).

4.2 Mechanical Durability

The inclusion of acrylic improves the resistance to cracking and UV aging, thereby increasing the service life in exterior and marine applications. In bend tests, hybrid coatings often exhibit better adhesion, impact resistance, and flexibility, which correlate with their ability to maintain integrity under deformation without cracking or deboning (Abd-Elnaiem et al., 2022; Guo et al., 2025).

Lyazzat et al. (2025) mentioned the fabrication of epoxy/ acrylics hybrid resin via the modification of epoxy resin (E0) with varying contents of 2 hydroxyethyl methacrylate (2-HEMA), using triethylamine (TEA) as a catalyst. The obtained epoxy/ acrylics hybrid resin improved durability and mechanical properties (adhesion strength (12 MPa) and tensile strength (69.8 MPa)), chemical stability, and corrosion resistance thereby contributing to sustainability in the coating industry. These improvements are attributed to the synergistic interaction between functional groups such as double bonds, hydroxyl, carbonyl, and ether moieties facilitating robust network formation within the hybrid matrix. Enhancements in chemical and solvent resistance, as well as mechanical integrity, were observed with increasing 2-HEMA content up to 30 %. However, at 40 % of 2-HEMA, the curing mechanism was disrupted, resulting in incomplete drying and compromised film formation.

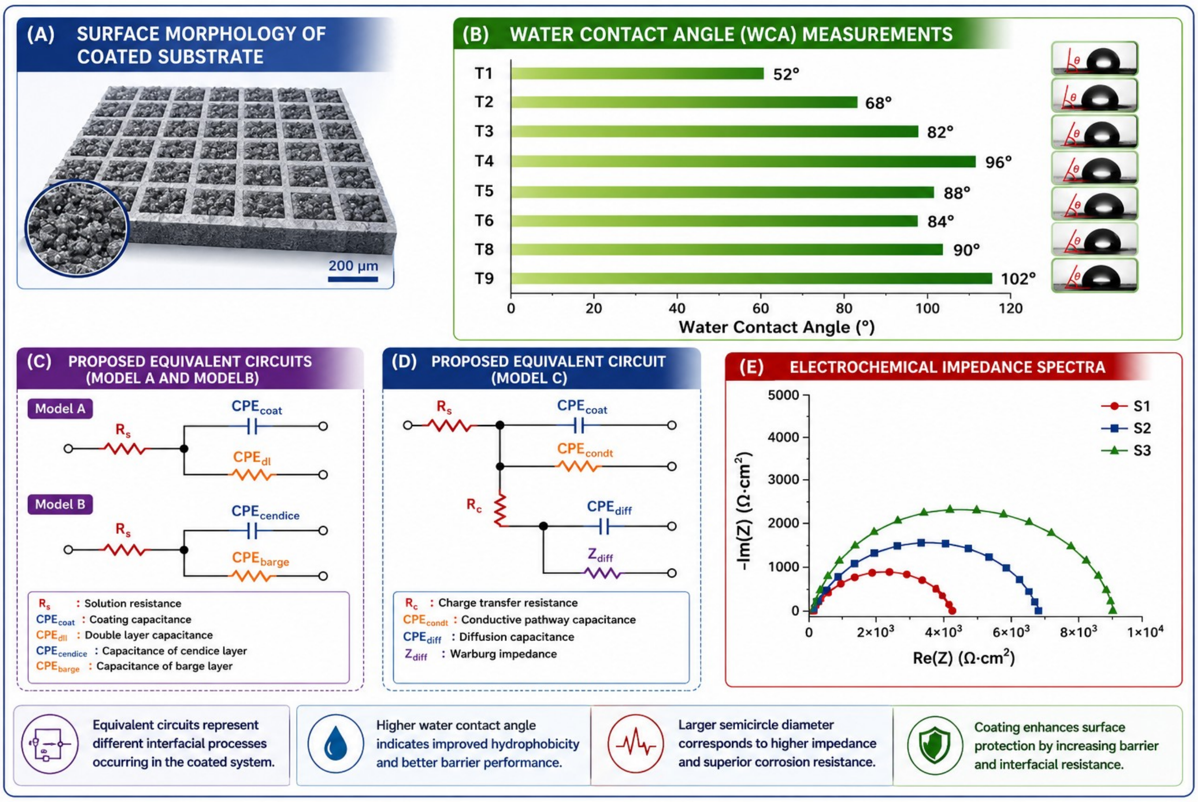

Figure 4 (a) CHT analysis of all coating systems. (b) Graphical analysis of the WCA measurements (degrees) of all coating samples with PDMS incorporation. (c) Schematic model of equivalent circuits used for fitting the impedance plots. (d) Nyquist plots of all composite coating samples modified with PDMS after 60 days of immersion.

4.2.1 Comparative Analysis of the Representative Studies

A comparison of the reviewed articles shows that chemically bonded hybrid materials are usually superior to physically mixed composites in terms of corrosion protection and protective coating stability. Studies using grafting techniques, copolymerization approaches, and structures have shown higher impedance and better protective abilities due to increased interface compatibility. Physically mixed composite coatings often exhibit phase separation and inferior long-term stability. The environmental benefits of water-based dispersion systems should be acknowledged, although some studies have reported lower corrosion resistance than solvent-based coatings. Table 2 summarizes the various hybridization strategies reported for epoxy–acrylic hybrid resins. Although such technologies have numerous advantages, several disadvantages still exist. First, waterborne coatings demonstrate a high level of environmental friendliness, but they do not demonstrate high barrier characteristics compared with solvent coatings. Second, nanocomposites help achieve higher corrosion resistance and increased coating durability, but particle aggregation and increased formulation cost are drawbacks. Third, although smart coatings have self-healing properties, they also have scalability and stability disadvantages. Finally, increasing crosslinking increases the barrier properties but decreases flexibility and increases the cracking susceptibility.

The evidence presented in the literature varies in quality. Studies that use a variety of complementary characterization techniques, such as electrochemical impedance spectroscopy (EIS), salt-spray exposure, immersion testing, adhesion measurements, and mechanical durability evaluations, more strongly support performance claims than studies that only use one testing methodology. Owing to their better phase compatibility and lower defect density, core-shell structures and chemically grafted systems consistently show the strongest evidence for increased corrosion resistance among the examined techniques. Physically blended systems frequently exhibit higher performance variability due to their vulnerability to phase separation. Although waterborne hybrid systems have several environmental benefits, emulsion stability, particle shape, and crosslink density still affect how well they corrode. These findings emphasize the need for uniform testing procedures to allow for a more thorough comparison of rival hybridization techniques.

Table 2 Representative studies on epoxy–acrylic hybrid anticorrosion coatings

Resin-Hybrid Type	Hybridization Route	Test Method	Main Performance Result	Limitation	References
Acrylic–epoxy hybrid coating	Adhesion and EIS techniques	Adhesion and corrosion tests	Improved adhesion and corrosion resistance compared with individual components.	Limited long-term durability evaluation.	Rau et al., 2012
Acrylic/silica-armored epoxy hybrid	Core–shell nanoparticle structure	Mechanical and fracture tests	Fracture toughness increased ∼8-fold and fracture energy by approximately ∼50-fold.	Corrosion performance was not extensively evaluated.	Gharieh et al., 2021
Waterborne epoxy/acrylic resin	Emulsion polymerization	Salt spray and thermal analysis	Stable emulsion (>9 months) with <5% rust after salt spray exposure.	Short exposure duration and limited field validation.	Chen et al., 2023b
Acrylic–epoxy–PDMS modified with graphene nanofillers	Chemical modification	EIS, adhesion, and water contact angle	Impedance exceeded 10^{10} Ω·cm^2 after 60 days of immersion, demonstrating excellent barrier performance.	Performance strongly depended on formulation composition.	Kumar et al., 2023b
Waterborne epoxy–acrylic emulsion	Graft copolymerization	Coating characterization and corrosion assessment	Improved environmental compatibility and coating stability with enhanced chemical resistance and durability.	Barrier properties remained lower than those of solvent-based systems.	Liu et al., 2023
Hybrid epoxy–acrylic emulsion	Waterborne hybrid formulation	Salt spray, immersion, and electrochemical testing	Superior corrosion resistance compared with pure acrylic coatings.	Requires long-term industrial-scale validation.	Guo et al., 2025
GMA-modified epoxy–acrylate hybrid	Copolymerization	Thermal and physicochemical characterization	Enhanced thermal stability and compatibility.	Corrosion behavior was not directly investigated.	Zhou et al., 2025a

4.3 Critical Analysis and Research Gaps

Despite the remarkable progress made in the development of epoxy-acrylic hybrid coatings in terms of corrosion protection, adhesion strength, and wear resistance, it is difficult to perform comparative evaluations based on existing scientific works because of differences in the chemical compositions of the resins used, curing techniques, substrate preparation methods, corrosion test procedures, and test environments. Thus, the positive results reported in the literature do not always arise from the effects of hybrids. In addition, most research employs only laboratory tests (salt spray tests, electrochemical impedance spectroscopy, etc.), while little is known about the practical outdoor performance of such coatings, and few works address the issues of scale-up, economy, or environmental safety. Hence, future work on the development of epoxy-acrylic hybrids should focus on rigorous experimental evaluations, outdoor studies, and comparisons among various hybrid formation strategies.

According to a critical review of the literature, not all investigations consistently support the purported superiority of epoxy–acrylic hybrid coatings. Graft copolymers, copolymerized networks, and core-shell architectures are examples of chemically bonded systems that typically exhibit superior corrosion resistance and long-term barrier performance. However, the degree of improvement varies greatly based on the formulation design and testing conditions. While some research claims outstanding salt-spray resistance and impedance levels above 10^{11} $\Omega \cdot cm^2$, others find only modest gains when compared to traditional epoxy systems. The main causes of these disparities are variations in resin composition, curing chemistry, filler content, substrate preparation, coating thickness, and exposure conditions. Additionally, the majority of published studies are still restricted to laboratory-scale assessments utilizing accelerated corrosion tests; comparatively few studies examine industrial implementation, life-cycle performance, long-term outdoor exposure, or economic viability. Therefore, even though there is a lot of evidence to support the promise of epoxy–acrylic hybrids for corrosion protection, it is still difficult to compare studies directly, and more standardized research is needed to create widely recognized performance benchmarks.

In addition to that, the development of new hybrid-polymer and their composites for advanced and development of new materials and versatile application including catalyst, additive and advanced building, such as rare earth elements (Kusrini et al., 2026) and biochar (Rizianiza et al., 2026) could be introduced in these materials or hybrid resins to increase the lifetime and function for furthermore research.

5. Conclusions

Epoxy–acrylic hybrid resins represent a significant advancement in anticorrosion coating technology. These hybrids provide improved mechanical performance, reduced defect formation, and enhanced long-term corrosion protection by integrating the strong adhesion and barrier properties of epoxy with the flexibility and environmental durability of acrylic polymers. Hybridization strategies and optimized network architectures are critical for achieving high performance, enhancing coating durability, and ensuring sustainability in waterborne or low-VOC systems. Epoxy–acrylic hybrids offer a versatile and industrially relevant platform for next-generation anticorrosion coatings. Corrosion evaluation results from salt spray exposure, electrochemical impedance spectroscopy, and immersion testing consistently show that epoxy–acrylic hybrid coatings outperform conventional single-component systems. These improvements are primarily attributed to reduced permeability to corrosive species, enhanced mechanical integrity, and improved adhesion stability in aggressive environments. Despite the challenges related to phase morphology control and formulation optimization, epoxy–acrylic hybrid resins present a versatile and scalable solution for high-performance, low-VOC corrosion-resistant coatings.

6. Future perspectives and challenges

The future development of epoxy–acrylic hybrid resins for anticorrosion paints will increasingly focus on achieving precise control over the phase morphology; optimizing dispersion and interfacial bonding, as well as increasing the crosslink density and interfacial compatibility, remains a key challenge. Although hybrid systems have demonstrated superior corrosion resistance, minimizing phase separation and ensuring long-term stability under fluctuating mechanical and environmental stresses remain challenges. Advanced polymer design strategies, including controlled radical polymerization and tailored functional monomers, are expected to play a key role in addressing these limitations. From an application perspective, the transition toward waterborne and low-VOC epoxy–acrylic hybrid coatings remain a critical challenge and will align corrosion coatings with environmental regulations and sustainability goals. Biobased monomers and greener synthesis routes are promising research directions. Although significant progress has been made, maintaining barrier performance and durability comparable to those of solvent-based systems requires further optimization. Additionally, the incorporation of nanofillers (e.g., graphene oxide, silica, and nanoclays) and corrosion inhibitors into epoxy–acrylic hybrids present opportunities for performance enhancement gains, especially in terms of barrier properties and mechanical reinforcement, but also raises concerns related to dispersion, scalability, and cost. Embedding responsive chemicals (e.g., self-healing microcapsules and corrosion inhibitors) within hybrid matrices may enhance long-term performance and enable adaptive protection. Addressing these challenges is essential for the widespread industrial adoption of next-generation epoxy–acrylic hybrid anticorrosion coatings.

Author contributions

Conceptualization and study design were carried out by Moshera Samy, Satpayev G. Ratpekovich, El-Sayed Negim, and Khaldun M. Al Azzam. Literature collection and data curation were performed by Puzikova Darya, Moshera Samy, Bekbayeva Lyazzat, and Khussurova Gulinur. Data analysis and interpretation were conducted by Zhurynov Murat, Kenzin Nail, and Nefedov Alexander. Visualization and figure preparation were carried out by Moshera Samy. The original draft of the manuscript was prepared by Khaldun M. Al Azzam, Puzikova Darya, and Satpayev G. Ratpekovich, while El-Sayed Negim, Khaldun M. Al Azzam, Zhurynov Murat, Eny Kusrini and Moshera Samy contributed to critical revision and editing of the manuscript. All authors reviewed, discussed, and approved the final version of the manuscript.

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Conflicts of interest

Authors declare no conflict of interest.

Data availability

The data that support the findings of this study are available in the published literature and are also cited in the present manuscript.

References

Aalto-Korte, K. (2019). Acrylic resins. In *Kanerva's occupational dermatology* (pp. 737–756). Springer International Publishing. https://doi.org/10.1007/978-3-319-68617-2_50

Abd-Elnaiem, A. M., Salman, O. S., Hakamy, A., & Hussein, S. I. (2022). Mechanical characteristics and thermal stability of hybrid epoxy and acrylic polymer coating/nanoclay of various thicknesses. *Journal of Inorganic and Organometallic Polymers and Materials*, *32*, 2094–2102. https://doi.org/10.1007/s10904-022-02270-8

Abiodun, M.-I. B., Oluwole, O. I., A., D. A., Ondieki, B. D., & Ibrahim, M. A. (2025). Applications of epoxy resin: Adhesives, coatings, and composites. In *Materials science*. IntechOpen. https://doi.org/10.5772/intechopen.1012261

Adnan, S. N. A., Kahar, N. E. A., Sobari, M. S., Mohamed, S. H., Chen, L. J., Lee, E., Pargi, M. N. F., & Musa, M. S. (2025). Effect of epoxy content on the corrosion properties of waterborne epoxy-acrylate coating. *Journal of Coatings Technology and Research*, *23*(2), 883–898. https://doi.org/10.1007/s11998-025-01175-8

Aljibori, H., Al-Amiery, A., & Isahak, W. N. R. (2024). Advancements in corrosion prevention techniques. *Journal of Bio- and Tribo-Corrosion*, *10*. https://doi.org/10.1007/s40735-024-00882-w

Al-Maharma, A. Y., Markert, B., & Bamer, F. (2025). The cellulose loading and silylation effects on the mechanical properties of epoxy composites: Insights from classical and reactive molecular dynamics simulations. *Polymers*, *17*(20), 2749. https://doi.org/10.3390/polym17202749

Anwar, S., & Li, X. (2024). A review of high-quality epoxy resins for corrosion-resistant applications. *Journal of Coatings Technology and Research*, *21*, 461–480. https://doi.org/10.1007/s11998-023-00865-5

Aronovich, D. A., & Boinovich, L. B. (2021). Structural acrylic adhesives: A critical review. In *Progress in adhesion and adhesives* (pp. 651–708). Wiley. https://doi.org/10.1002/9781119846703.ch15

Aslam, R., Yan, Z., Wang, Q., & Aslam, J. (Eds.). (2025). *Architectural corrosion and critical infrastructure*. Royal Society of Chemistry. https://doi.org/10.1039/9781837678259

Aziz, T., Ullah, A., Fan, H., Jamil, M. I., Khan, F. U., Ullah, R., Iqbal, M., Ali, A., & Ullah, B. (2021). Recent progress in silane coupling agent with its emerging applications. *Journal of Polymers and the Environment*, *29*, 3427–3443. https://doi.org/10.1007/s10924-021-02142-1

Bednarczyk, P., Irska, I., Gziut, K., & Ossowicz-Rupniewska, P. (2021). Novel multifunctional epoxy (meth)acrylate resins and coatings preparation via cationic and free-radical photopolymerization. *Polymers*, *13*(11), 1718. https://doi.org/10.3390/polym13111718

Bernacki, H., Fu, Z., Li, B., Lindenmuth, D., & Procopio, L. (2018). Enhancing the UV durability of epoxy coatings: Waterborne acrylic-epoxy hybrid coatings for steel. In *SSPC 2018* (pp. 1–51). SSPC. https://doi.org/10.5006/s2018-00054

Bhat, S. I., Mobin, M., Islam, S., Zehra, S., & Shahid-ul-Islam. (2024). Recent advances in anticorrosive coatings based on sustainable polymers: Challenges and perspectives. *Surface and Coatings Technology*, *480*, 130596. https://doi.org/10.1016/j.surfcoat.2024.130596

Cardona, F., Sultan, M. T. B. H., Abu Talib, A. R., Ezzah, F., & Derahman, A. (2016). Interpenetrating polymer network (IPN) with epoxidized and acrylated bioresins and their composites with glass and jute fibres. *BioResources*, *11*(1). https://doi.org/10.15376/biores.11.1.2820-2838

Çetinkaya, H. F., Seyran, E., Çetinkaya, S., & Tüzün, B. (2025). Corrosion protection coatings in industrial materials: Methods and innovations. In *ACS Symposium Series* (pp. 133–162). American Chemical Society. https://doi.org/10.1021/bk-2025-1503.ch007

Cheaburu-Yilmaz, C. N., Ozkan, C. K., & Yilmaz, O. (2022). Synthesis and application of reactive acrylic latexes: Effect of particle morphology. *Polymers*, *14*(11), 2187. https://doi.org/10.3390/polym14112187

Chen, L., Hong, L., Lin, J.-C., Meyers, G., Harris, J., & Radler, M. (2016). Epoxy-acrylic core-shell particles by seeded emulsion polymerization. *Journal of Colloid and Interface Science*, *473*, 182–189. https://doi.org/10.1016/j.jcis.2016.04.005

Chen, X., Xiao, Y., Liu, R., Zhang, K., & Zhao, J. (2023a). Preparation and properties of one-component self-cross-linking stabilized epoxy-acrylate composite emulsion. *Colloid and Polymer Science*, *302*(3), 289–302. https://doi.org/10.1007/s00396-023-05163-5

Chen, Y.-C., Huang, Y.-C., Wu, C.-H., Lin, H.-W., Chiu, W.-Y., Jeng, R.-J., & Tung, S.-H. (2023b). Waterborne epoxy/acrylic resins stabilized through the neutralization of basic amine-modified epoxy and acidic acrylic copolymers. *ACS Applied Polymer Materials*, *6*, 828–836. https://doi.org/10.1021/acsapm.3c02424

del Castillo, A., Paulis, M., & González, E. (2025). Direct-to-metal binders for waterborne anticorrosive steel coatings: Epoxy/styrene-acrylic blends and hybrids. *Reactive and Functional Polymers*, *215*, 106378. https://doi.org/10.1016/j.reactfunctpolym.2025.106378

Demiral, M. (2025). Strength in adhesion: A multi-mechanics review covering tensile, shear, fracture, fatigue, creep, and impact behavior of polymer bonding in composites. *Polymers*, *17*, 2600. https://doi.org/10.3390/polym17192600

Deng, E., Dai, X., Zhang, L., Zheng, T., Liu, X., & Shen, J. (2025). High-efficient toughening and strengthening of epoxy resin with organic–inorganic core–shell nanoparticles. *Composites*

Part A: Applied Science and Manufacturing, *198*, 109113. https://doi.org/10.1016/j.compositesa.2025.109113

Ercan, B. T., Mutlu, A., Gultekin, S. S., Gultekin, B., Dincalp, H., & Zafer, C. (2025). Improved mechanical and physical properties of epoxy acrylate oligomers by chemical modification for the effective encapsulation of the triple-cation perovskite solar cells. *ACS Omega*, *10*(19), 19723–19734. https://doi.org/10.1021/acsomega.5c00860

Eyann, L., Ariff, Z. M., Shafiq, M. D., Shuib, R. K., & Musa, M. S. (2024). Investigating the effect of methacrylic acid on the properties of waterborne epoxy-acrylate core-shell emulsion, film and coating. *Progress in Organic Coatings*, *187*, 108096. https://doi.org/10.1016/j.porgcoat.2023.108096

Faccini, M., Bautista, L., Soldi, L., Escobar, A. M., Altavilla, M., Calvet, M., Domènech, A., & Domínguez, E. (2021). Environmentally friendly anticorrosive polymeric coatings. *Applied Sciences*, *11*, 3446. https://doi.org/10.3390/app11083446

Fang, B., Zhang, X., Liu, H., Zhao, F., Li, Y., Zeng, X., Feng, Z., Li, W., & Liu, J. (2025). Improved anti-corrosion performance of epoxy coatings based on pH-sensitive gels loaded with inhibitors. *Journal of Materials Research and Technology*, *34*, 1682–1690. https://doi.org/10.1016/j.jmrt.2024.12.160

Flosbach, C., & Fugier, R. (2010). Epoxy functional acrylic polymers for high performance coating applications. In *Epoxy polymers* (pp. 39–54). Wiley. https://doi.org/10.1002/9783527628704.ch3

Fu, H., & Wang, C. (2025). Performance evaluation of waterborne epoxy resin-reinforced SBS, waterborne acrylate or SBR emulsion for road. *Coatings*, *15*, 787. https://doi.org/10.3390/coatings15070787

Gao, J., Li, C., Lv, Z., Wang, R., Wu, D., & Li, X. (2019). Correlation between the surface aging of acrylic polyurethane coatings and environmental factors. *Progress in Organic Coatings*, *132*, 362–369. https://doi.org/10.1016/j.porgcoat.2019.04.009

Gawali, S. K., & Jain, P. K. (2026). Effect of natural weathering conditioning on the mechanical and surface performance of additively manufactured acrylonitrile styrene acrylate (ASA) components. *Arabian Journal for Science and Engineering*, *51*(14), 17465–17492. https://doi.org/10.1007/s13369-026-11212-2

Gharieh, A., Moghadas, M., & Pourghasem, M. (2021). Synergistic effects of acrylic/silica armored structured nanoparticles on the toughness and physicomechanical properties of epoxy polymers. *ACS Applied Polymer Materials*, *3*, 4008–4016. https://doi.org/10.1021/acsapm.1c00530

Gong, Y., Cui, J., Qin, Z., Wang, L., Ao, Y., Liu, Y., & Shang, L. (2024). Enhancing strength, toughness, and flame retardancy of epoxy resins through in-situ interpenetrating network modification. *Materials Today Communications*, *39*, 109233. https://doi.org/10.1016/j.mtcomm.2024.109233

Guo, L., Wang, Y., Zhang, J., Li, W., & Zhao, Z. (2025). Preparation of hybrid epoxy acrylic emulsion and its application in anti-corrosion coatings. *Journal of Applied Polymer Science*, *143*(11). https://doi.org/10.1002/app.70233

Hao, J., Yang, K., Wu, J., Wu, M., & Li, Y. (2025). Overview of recent developments in composite epoxy resin in organic coating on steel (2020–2024). *Materials*, *18*, 1531. https://doi.org/10.3390/ma18071531

Huang, S., Chen, Z., Chen, W., & Jiang, D. (2025). Improved toughness, flexural strength, and dielectric performances of epoxy-dicyclopentadiene interpenetrating polymer networks via simultaneous frontal polymerization. *ACS Applied Polymer Materials*, *7*(15), 9920–9932. https://doi.org/10.1021/acsapm.5c01563

Im, S., Kim, K., Yun, M., Cho, T.-Y., Eom, J.-H., & Cho, S.-K. (2024). Cross-link density and moisture barrier properties of organic films prepared by the dual curing of epoxy–acrylate hybrid networks in various solvents. *Progress in Organic Coatings*, *191*, 108443. https://doi.org/10.1016/j.porgcoat.2024.108443

Jiao, C., Shao, Q., Wu, M., Zheng, B., Guo, Z., Yi, J., Zhang, J., Lin, J., Wu, S., Dong, M., & Guo, Z. (2020). 2-(3,4-epoxy) ethyltriethoxysilane-modified waterborne acrylic resin: Preparation and property analysis. *Polymer*, *190*, 122196. https://doi.org/10.1016/j.polymer.2020.122196

Jing, H., Mu, X., Wang, Q., Cui, Y., & Sun, C. (2023). Preparation and performance analysis of epoxy acrylic resin for repairing asphalt pavement diseases. *Journal of Engineering Science and Technology Review*, *16*(1), 92–100. https://doi.org/10.25103/jestr.161.12

Jurinovs, M., Rukavisnikovs, N., Greivule, S., Starkova, O., Kovalovs, A., Brunāvs, J., Macutkevič, J., Juhnevica, I., Platnieks, O., & Gaidukovs, S. (2026). Nanostructure-reinforced epoxy-acrylate interpenetrated networks for UV-curable high-performance coatings. *Reactive and Functional Polymers*, *221*, 106664. https://doi.org/10.1016/j.reactfunctpolym.2026.106664

Kania, H. (2023). Corrosion and anticorrosion of alloys/metals: The important global issue. *Coatings*, *13*, 216. https://doi.org/10.3390/coatings13020216

Kardar, P., & Amini, R. (2026). Advances and future directions in eco-friendly coatings: From chemistry to industrial applications. *Progress in Organic Coatings*, *214*, 110068. https://doi.org/10.1016/j.porgcoat.2026.110068

Kausar, A. (2019). Performance of corrosion protective epoxy blend-based nanocomposite coatings: A review. *Polymer-Plastics Technology and Materials*, *59*, 658–673. https://doi.org/10.1080/25740881.2019.1673410

Kim, J., Kang, S., Seong, I., Jeon, J. W., Lee, D., Kim, J.-H., & Kwon, D.-J. (2025). Advancing CFRP durability: Interfacial and weathering performance of epoxy and acrylic matrices. *Composites Part B: Engineering*, *297*, 112315. https://doi.org/10.1016/j.compositesb.2025.112315

Kotb, Y., Serfass, C. M., Cagnard, A., Houston, K. R., Khan, S. A., Hsiao, L. C., & Velev, O. D. (2023). Molecular structure effects on the mechanisms of corrosion protection of model epoxy coatings on metals. *Materials Chemistry Frontiers*, *7*(2), 274–286. https://doi.org/10.1039/d2qm01045c

Kotnarowska, D. (2018). Influence of ageing with UV radiation on physicochemical properties of acrylic-polyurethane coatings. *Journal of Surface Engineered Materials and Advanced Technology*, *08*, 95–109. https://doi.org/10.4236/jsemat.2018.84009

Kumar, S. S., Wonnie Ma, I. A., Ong, G., Ramesh, K., & Ramesh, S. (2023a). An insight on the corrosive performance of acrylic-epoxy based coatings: The significance of its electrochemical impedance evaluations. *Journal of Polymer Research*, *30*. https://doi.org/10.1007/s10965-023-03574-0

Kumar, S. S., Wonnie Ma, I. A., Ramesh, K., & Ramesh, S. (2023b). Development of graphene incorporated acrylic-epoxy composite hybrid anti-corrosion coatings for corrosion protection. *Materials Chemistry and Physics*, *303*, 127731. https://doi.org/10.1016/j.matchemphys.2023.127731

Kusrini, E., Prihandini, W. W., Suhendra, B., Prasetyo, A. B., Usman, A., Ivo, P., Suyanti, Manawan, M., Rahardjo, S., & Wilson, L. D. (2026). Recovery of critical rare earth elements from belitung silica sand: A pyro-hydrometallurgical process and economic feasibility analysis. *Journal of Sustainable Metallurgy*, *12*, 3899–3919. https://doi.org/10.1007/s40831-026-01529-5

Liu, J., Zhang, Y., & Sun, J. (2023). Preparation and performance of a self-produced high-molecular-weight waterborne epoxy–acrylic emulsion. *Coatings*, *13*, 595. https://doi.org/10.3390/coatings13030595

Liu, X. (2025). Review of protective coatings for corrosion mitigation in chemical machinery: Performance and mechanical aspects. *Journal of Adhesion Science and Technology, 1–50.* https://doi.org/10.1080/01694243.2025.2599172

Lyazzat, B., Negim, E.-S., Al Azzam, K. M., Zhanibekov, R., Sergeevna, P. D., Rashidovich, K. N., Zhurynovich, Z. M., Nikolayevich, N. A., Marsovna, K. G., & Ewies, E. F. (2025).

Viscosity and physicomechanical properties of epoxy/2-hydroxyethyl methacrylate hybrid coatings for advanced anti-corrosion applications. *Egyptian Journal of Petroleum*, *34*. https://doi.org/10.62593/2090-2468.1083

Ma, Y., Liu, Z., Li, P., Li, M., & Zhao, Y. (2022). Fabrication of epoxy resin/acrylate IPNs magnetorheological material with oil-surface bonding for damage repair of long-distance oil pipelines. *Cement and Concrete Composites*, *131*, 104572. https://doi.org/10.1016/j.cemconcomp.2022.104572

Makhmetova, A., Negim, E.-S., Ainakulova, D., Yeligbayeva, G., & Khatib, J. (2023). An overview of epoxy resins as coating to protect metals from corrosion. *Kompleksnoe Ispol'zovanie Mineral'nogo Syr'â*, *328*, 20–32. https://doi.org/10.31643/2024/6445.03

Manu, K. C., Madhushree, C., Chandini, M. S., Shree, N., Hemanth, S., & Jeevan, T. P. (2025). Corrosion in steel structures: A review. *Journal of Mines, Metals and Fuels*, *73*, 189–198. https://doi.org/10.18311/jmmf/2025/46985

Mohanty, D., Mohanty, S., & Kanny, K. (2025). Role of additives in waterborne epoxy coatings. In *Materials horizons: From nature to nanomaterials* (pp. 37–62). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-3260-2_3

Muradova, S., Negim, E.-S., Makhmetova, A., Ainakulova, D., & Mohamad, N. M. I. (2023). An overview of the current state and the advantages of using acrylic resins as anticorrosive coatings. *Complex Use of Mineral Resources*, *327*, 90–98. https://doi.org/10.31643/2023/6445.44

Muthukumaran, N. (2026). Corrosion influencing factors: Environmental, material and electrochemical perspectives. In *Materials research foundations* (pp. 120–138). Materials Research Forum LLC. https://doi.org/10.21741/9781644903919-6

Nasirzadeh, M., Ebrahimi, M., & Zahedi, S. (2025). Tailoring self-stratification in epoxy-acrylic/ATH coatings: Effects of resin selection and filler incorporation method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *725*, 137694. https://doi.org/10.1016/j.colsurfa.2025.137694

Naveed, M., Asif, M., & Saif, M. J. (2026). Halloysite nanotubes reinforced epoxy/epoxy acrylate blends: Unlocking the potential of hybrid nanocomposites. *Polymers*, *18*(5), 554. https://doi.org/10.3390/polym18050554

Negim, E.-S., Bekbayeva, L., Puzikova, D. S., Zhurynov, M. Z., Nefedov, A. N., Khussurova, G. M., Shadin, N. A., & Khatib, J. (2025). Epoxy resin development for anticorrosion coatings. *Complex Use of Mineral Resources*, *338*, 13–20. https://doi.org/10.31643/2026/6445.24

Oliveira, K. W. d., Faccioli, Y. E. d. S., de Araújo, G. P., Converti, A., da Silva, R. d. C. F. S., & Sarubbo, L. A. (2026). From the problem of corrosion to green solutions: The role of biosurfactants as anti-corrosion agents. *Materials*, *19*, 743. https://doi.org/10.3390/ma19040743

Pieters, K., & Mekonnen, T. H. (2024). Progress in waterborne polymer dispersions for coating applications: Commercialized systems and new trends. *RSC Sustainability*, *2*(12), 3704–3729. https://doi.org/10.1039/d4su00267a

Pojnar, K., Pilch-Pitera, B., & Patil, R. (2024). Progress in the development of acrylic resin-based powder coatings – an overview. *Polimery*, *69*(3). https://doi.org/10.14314/polimery.2024.3.1

Pozo-Antonio, J. S., Alonso-Villar, E. M., Rivas, T., & Márquez, I. (2023). Evaluation of a protective acrylic finish applied to surfaces painted with acrylic paints for outdoor or indoor uses. *Dyes and Pigments*, *212*, 111141. https://doi.org/10.1016/j.dyepig.2023.111141

Priyadharshini, R., & Xavier, J. R. (2026). Innovative graphene-based nanocomposite coatings for advanced corrosion resistance in the automotive industry. *Materials and Corrosion*. https://doi.org/10.1002/maco.70106

Procopio, L. (2020). The evolution of waterborne acrylic protective coatings. In *Coatings+ 2020* (pp. 1–29). SSPC. https://doi.org/10.5006/s2020-00048

Rau, S. R., Vengadaesvaran, B., Ramesh, K., & Arof, A. K. (2012). Studies on the adhesion and corrosion performance of an acrylic-epoxy hybrid coating. *The Journal of Adhesion*, *88*, 282–293. https://doi.org/10.1080/00218464.2012.659646

Rizianiza, I., Kusrini, E., Siswantara, A. I., Aziz, M., Ivo, P., Maknun, I. J., Ichsan, R. R., Ummatin, K. K., & Usman, A. (2026). Biomass-derived biochar as a precursor for graphene-like carbon materials via slow pyrolysis: A review. *Journal of Environmental Chemical Engineering*, *14*, 122685. https://doi.org/10.1016/j.jece.2026.122685

Saikia, M., Dutta, T., Jadhav, N., & Kalita, D. J. (2025). Insights into the development of corrosion protection coatings. *Polymers*, *17*, 1548. https://doi.org/10.3390/polym17111548

Samoilenko, T. F., Yarova, N. V., Yashchenko, L. M., & Brovko, O. O. (2024). UV-cured epoxy-acrylate interpenetrating polymer networks. *Journal of Applied Polymer Science*, *141*. https://doi.org/10.1002/app.55974

Shoily, S. K., Sajib, M. A. R., Islam, M. S., & Arifuzzaman, M. (2025). Tailoring interfacial adhesion and hydrophobicity in jute-epoxy composites via acrylic water sealer coatings. *Hybrid Advances*, *11*, 100558. https://doi.org/10.1016/j.hybadv.2025.100558

Shojaei, A. R., Ramezanzadeh, B., & Mohammadloo, H. E. (2025). Corrosion in the marine and offshore industry. In *Industrial corrosion* (pp. 65–104). Wiley. https://doi.org/10.1002/9781394301560.ch4

Sinha, S., & Dey, K. P. (2025). Advancements and diverse applications of waterborne epoxy coatings: A comprehensive review. In *Materials horizons: From nature to nanomaterials* (pp. 245–256). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-3260-2_12

Srikanth, P. S. (2026). Factors affecting corrosion. In *Materials research foundations* (pp. 35–54). Materials Research Forum LLC. https://doi.org/10.21741/9781644903919-3

Subbiah, K., Sonwani, R. K., Sinha, T., Gope, S., Chawla, R., & Pal, D. (2025). Corrosion mechanisms and anti-corrosive coatings for mild steel in industrial environments. *ChemBioEng Reviews*, *13*. https://doi.org/10.1002/cben.70036

Tu, J., Moran, V. J., Rooney, E. E., Palmese, G. R., & Stanzione, J. F. (2024). Epoxy-methacrylate interpenetrating polymer networks. *Polymer*, *304*, 127130. https://doi.org/10.1016/j.polymer.2024.127130

Tulegenkyzy, A. D., Megat-Yusoff, P. S. M., Al Azzam, K. M., Kairatovna, B. L., Goyal, A., Eshmaiel, G., Negim, E., Kusrini, E., & Samy, M. (2025). Tailoring epoxy resin properties using glycidyl methacrylate-based reactive diluents. *International Journal of Technology*, *16*, 1421. https://doi.org/10.14716/ijtech.v16i4.7687

Tulegenkyzy, A. D., Megat-Yusoff, P. S. M., Al Azzam, K. M., Kairatovna, B. L., Goyal, A., Eshmaiel, G., Negim, E., Samy, M., & Ravindran, B. (2024). Poly(styrene-co-glycidyl methacrylate) reactive diluents. *International Journal of Technology*, *15*(4), 903–916. https://doi.org/10.14716/ijtech.v15i4.6920

Valeriia, T. (2025). Comparative analysis of hard gel and acrylic systems in modern nail industry. *Universal Library of Arts and Humanities*, *02*, 40–46. https://doi.org/10.70315/uloap.ulahu.2025.0203007

Vignesh, J., Ramesh, B., & Xavier, J. R. (2026). Development of hybrid coating systems for concrete steel structures. *Journal of Adhesion Science and Technology*. https://doi.org/10.1080/01694243.2026.2614359

Wang, M., Xiao, G., Wang, F., Ma, X., Liu, S., Yan, H., Gou, J., Cao, J., & Wang, Y. (2025). Catalytic crosslinking of epoxy coatings via BN-based hybrid materials for enhanced corrosion resistance, self-healing capabilities and mechanical properties. *Chemical Engineering Journal*, *515*, 163653. https://doi.org/10.1016/j.cej.2025.163653

Wang, X., Lu, M., Zhang, T., Xiong, X., Xia, L., & Guan, R. (2014). Facile fabrication and modification of epoxy acrylate latexes by epoxy resin and silane coupling agent. *Journal* *of Adhesion Science and Technology*, *29*(2), 94–108. https://doi.org/10.1080/01694243.2014.975914

Wang, X., Tebyetekerwa, M., Chen, Y., Sun, X., Cong, W., Wang, X., Chen, L., Li, Z., Gui, T., & Li, W. (2024). Improving the performance of acrylic-epoxy ester hybrid coatings with phosphate monomers. *Polymer Chemistry*, *15*(22), 2265–2276. https://doi.org/10.1039/d4py00131a

Xia, H., Yue, Y., Li, X., Song, L., Lu, C., Cui, L., & Niu, Y. (2025). Highly flexible acrylic–epoxy resin with self-stratification waterproof material. *Journal of Materials in Civil Engineering*, *37*. https://doi.org/10.1061/jmcee7.mteng-20293

Xiao, F., Yong, T., Cao, T., Shi, F., Sun, X., & Zhang, J. (2024). Preparation and properties of waterborne acrylic-modified epoxy phosphate resin and its coating. *Coatings*, *14*(9), 1129. https://doi.org/10.3390/coatings14091129

Xiao, M., Zhang, J., & Feng, Y. (2025). Application of acrylate emulsion/resin in cement additives. *Polymers for Advanced Technologies*, *36*. https://doi.org/10.1002/pat.70218

Xie, T., Kao, W., Zhang, Z., Liu, Y., & Li, Z. (2021). Synthesis and characterization of organosilicon modified self-matting acrylate polymer: Insight into surface roughness and microphase separation behavior. *Progress in Organic Coatings*, *157*, 106300. https://doi.org/10.1016/j.porgcoat.2021.106300

Yadav, L., Sihmar, A., Kumar, S., Dhaiya, H., & Vishwakarma, R. (2024). Review of nano-based smart coatings for corrosion mitigation. *Environmental Science and Pollution Research*, *32*, 17032–17058. https://doi.org/10.1007/s11356-024-33234-9

Yao, M., Tang, E., Guo, C., Liu, S., Tian, H., & Gao, H. (2017). Waterborne epoxy/polyacrylate composites via miniemulsion polymerization. *Progress in Organic Coatings*, *113*, 143–150. https://doi.org/10.1016/j.porgcoat.2017.09.008

Yin, C., Wei, C. q., Li, G., Zhang, X. m., Zhang, X., Zhang, F., Wang, T., & Wu, F. (2025). Construction of superhydrophobic interface and anticorrosion mechanism of basalt flake/fluorinated-epoxy-acrylic composite coating. *Polymer Engineering & Science*, *66*(1), 513–530. https://doi.org/10.1002/pen.70235

Zade, G. S., & Patil, K. D. (2024). Advances in corrosion-resistant coatings. In *Functional coatings* (pp. 110–152). Wiley. https://doi.org/10.1002/9781394207305.ch5

Zaghloul, M. M. Y., Zaghloul, M. M. Y., & Fuseini, M. (2023). Recent progress in epoxy nanocomposites. *Polymers for Advanced Technologies*, *34*, 3438–3472. https://doi.org/10.1002/pat.6144

Zeng, P., Zhou, Y., Li, S., Wang, X., S.N, K., & A.R, T. (2025). Enhancement of concrete durability with waterborne acrylic resin. *International Journal of Multidisciplinary Research*, *1*, 9–18. https://doi.org/10.65231/ijmr.v1i2.16

Zhang, J., Zhang, Z., Huang, R., & Tan, L. (2025). Advances in toughening modification methods for epoxy resins. *Polymers*, *17*, 1288. https://doi.org/10.3390/polym17091288

Zhang, K., Chen, X., Xiao, Y., Liu, R., & Liu, J. (2021). Enhanced anticorrosion properties through structured particle design of waterborne epoxy-styrene-acrylate composite emulsion. *Coatings*, *11*(11), 1422. https://doi.org/10.3390/coatings11111422

Zhang, Z., Dong, J., Ma, M., Chen, W., Wang, H., Qian, H., & Fan, F. (2026). Corrigendum to "the aging behavior and failure mechanism of epoxy-acrylic polyurethane coating system under different accelerated testing methods".[eng. fail. anal. 188 (2026) 110650]. *Engineering Failure Analysis*, *190*, 110736. https://doi.org/10.1016/j.engfailanal.2026.110736

Zheng, B., Ge, S., Wang, S., Shao, Q., Jiao, C., Liu, M., Das, R., Dong, B., & Guo, Z. (2020). Effect of γ-aminopropyltriethoxysilane on the properties of cellulose acetate butyrate modified acrylic waterborne coatings. *Reactive and Functional Polymers*, *154*, 104657. https://doi.org/10.1016/j.reactfunctpolym.2020.104657

Zhou, S., Ma, J., Yu, J.-W., Gao, Z., Li, F., Zhang, F., & He, Y.-P. (2025a). Preparation and properties of epoxy modified acrylic polymer. *Polymers*, *17*, 380. https://doi.org/10.3390/polym17030380

Zhou, Y., Xu, G., Fan, Y., Li, Y., Chen, X., Yang, J., & Huang, W. (2025b). Multi-objective toughness optimization of epoxy resin for steel bridge deck pavement. *Polymers*, *17*, 1422. https://doi.org/10.3390/polym17101422

Zhu, X., Wang, Y., Wang, R., Bai, H., Xiang, Y., Ren, Q., Wang, C., Meng, X., Peng, G., & Wei, F. (2026). Synergistic enhancement of anti-corrosion performance by acrylate-epoxy hybrid emulsion and functionalized boron nitride. *Polymers for Advanced Technologies*, *37*(6). https://doi.org/10.1002/pat.70640

Zhu, Z., Li, R., Zhang, C., & Gong, S. (2018). Preparation and properties of high solid content and low viscosity waterborne polyurethane—acrylate emulsion with a reactive emulsifier. *Polymers*, *10*(2), 154. https://doi.org/10.3390/polym10020154