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Editorial: Development of high-performance resin matrix composites—volume II

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Editorial on the Research Topic
Development of high-performance resin matrix composites—volume II

1 Introduction

The field of materials science is undergoing a transformative shift toward designing materials that integrate functionality, sustainability, and mechanical robustness. In the Research Topic "Development of High-Performance Resin Matrix Composites-Volume II," four articles are presented and featured in this Research Topic exemplify this trend, addressing critical challenges in (1) wide-band shielding, (2) self-healing polymers, (3) recyclable thermosets, and (4) interfacial engineering for composites. These research efforts collectively push the boundaries of material performance while prioritizing environmental responsibility and practical applications.

2 Wide-band shielding materials for multifunctional protection

The increasing demand for advanced protective materials in extreme environments, particularly in aerospace and military applications, has driven significant research into multifunctional polymer composites. Exposured to intense solar radiation, including ultraviolet (UV), visible, and near-infrared wavelengths, structural materials could be degraded, and the lifespan of critical systems will be reduced. Traditional light-shielding materials have some limitations, such as narrow-spectrum protection, poor mechanical performance, or excessive weight. Poly (vinylidene fluoride) (PVDF), a fluoropolymer with excellent chemical stability and processability, has emerged as a promising matrix for such applications. However, achieving simultaneous broadband light blocking, high whiteness (for thermal reflectivity), and enhanced mechanical properties remains a challenge, necessitating innovative filler design and interfacial engineering.

The development of PVDF composite films with broad-spectrum light shielding capabilities represents a significant advancement in protective materials. By integrating polydopamine (PDA) modified $CsxWO_3$ ($CsxWO_3$@PDA) and TiO_2, Fu et al. found that the synergistic filler design could help the composites achieve whiteness levels above 74 and transmittance less than 5% across 200–2,500 nm, with near-zero transmittance below 1750 nm. This approach not only enhanced solar radiation blocking but also improved tensile strength by 14.8% through hydrogen bonding-mediated interfacial compatibility. Such materials hold promise for aerospace envelope systems and inflatable structures, where UV resistance and mechanical durability are paramount.

3 Bio-based self-healing polymers for sustainable engineering

The growing emphasis on sustainable engineering has spurred significant interest in bio-based polymers as alternatives to conventional petroleum-derived materials. Traditional self-healing polymers often rely on synthetic petrochemical feedstocks, raising concerns over environmental impact and long-term resource availability. Additionally, there are always high energy input (e.g., heat or UV light) required to trigger repair, which limited their applicability in biomedical or infrastructure settings where mild, autonomous healing is preferred. Vanillin, a lignin-derived compound, offers a renewable and chemically versatile platform for designing dynamic polymers, but balancing mechanical robustness with efficient self-repair at physiologically relevant temperatures remains a challenge.

To address these limitations, Fu et al. fabricated vanillin-based polyurethanes (VPUs) that integrated dynamic imine bonds and hydrogen-bonded networks, enabling rapid, body-temperature-activated healing without sacrificing performance. VPUs incorporating imine bonds could recover 98% of their original stress within 20 min at 36°C, enabled by hydrogen bond-mediated segmental mobility and microphase separation. The study showed that adjusting hard segment content (32.3%–53.3%) could tune both mechanical strength (up to 29.1 MPa) and healing efficiency, offering a blueprint for bioresorbable implants and self-repairing infrastructure materials. This work bridges the gap between sustainability and functionality, as vanillin-derived components reduce reliance on petrochemical feedstocks.

4 Recyclable epoxy vitrimers for circular economy applications

The widespread use of thermoset polymers in high-performance industries-such as aerospace, automotive, and wind energy-has long been hindered by their inherent irreversibility, making them difficult to recycle or reprocess. Conventional epoxy resins, while prized for their mechanical strength and thermal stability, generate significant waste at end-of-life due to permanent crosslinked networks. Recent advances in vitrimer chemistry, which introduce dynamic covalent bonds into thermosets, offer a promising solution by enabling reprocessability without sacrificing performance. However, many vitrimer systems still face trade-offs between recyclability and high-temperature stability, or rely on complex synthesis routes incompatible with industrial-scale production.

Gao et al. tackled these challenges by transforming a commercial epoxy-anhydride system into a high-performance vitrimer through strategic catalyst selection. And the results showed that efficient closed-loop recycling could coexist with the demanding requirements of structural composites. With 1,5,7-triazabicyclo [4.4.0]dec-5-ene (TBD) as a catalyst, these vitrimers exhibited enhanced cross-linking density (1,358 mol/m^3), glass transition temperature (132°C), and stress relaxation kinetics (τ^*= 10 min at 200°C). The materials could degrade completely in monoethanolamine at 160°C within 1 h, enabling full recovery of carbon fibers from composites. This breakthrough paves the way for "cradle-to-cradle" manufacturing in aerospace and wind energy sectors, where end-of-life recyclability is critical.

5 Interfacial engineering for high-performance composites

The pursuit of high-performance composites for aerospace and structural applications has long been constrained by interfacial weaknesses between reinforcing fibers and polymer matrices. Carbon fiber composites, despite their exceptional strength-to-weight ratios, often suffer from suboptimal load transfer due to poor fiber-matrix adhesion, leading to delamination and premature failure under mechanical stress. Traditional sizing agents-protective coatings applied to fibers during manufacturing-have primarily focused on processing aids rather than interfacial reinforcement. While epoxy (EP)-based sizings dominate the industry, their chemical mismatch with alternative matrix resins (e.g., vinyl esters (VE)) limits composite performance. Recent studies highlight the untapped potential of interfacial engineering through tailored sizing chemistry, where surface oxygen functionalization and active carbon sites could dramatically enhance bonding. However, systematic comparisons of sizing-matrix compatibility and its quantitative impact on critical properties like interlaminar shear and compressive strength remain underexplored.

Ouyang et al. addressed the gap by rigorously evaluating how epoxy and vinyl ester sizing agents modulate interfacial chemistry and mechanical outcomes, offering a roadmap for next-generation composites where damage tolerance and weight savings are paramount. EP and vinyl ester VE sizing agents could increase the oxygen content on carbon fiber surfaces by 13.0%–18.1% and active carbon atom ratios by 11.3%–20.3%, improving interlaminar shear strength by up to 20.0%. VE-sizing enhanced open-hole compressive strength by 6.7% relative to EP, demonstrating that chemical compatibility between sizing and matrix resin is pivotal for load transfer. These findings guide the design of next-generation composites for aerospace structures, where impact resistance and damage tolerance are non-negotiable.

6 Conclusion

In summary, this Research Topic on "Development of High-Performance Resin Matrix Composites-Volume II" presents collectively advance materials science toward three overarching goals: functional integration, sustainability, and interfacial precision. By combining dynamic bonds, bio-based monomers, and recyclable chemistries, these works exemplify how material design can address global challenges in energy, infrastructure, and environmental stewardship. Future research should prioritize scaling these innovations for industrial adoption, exploring multi-functional hybrids (e.g., self-healing vitrimers or shielded composites), and integrating artificial intelligence for accelerated material discovery. The convergence of these frontiers promises to drive the next-generation of sustainable technologies, where materials not only perform optimally but also contribute to a circular global economy.

Author contributions

CZ: Writing – original draft. SL: Writing – original draft. YL: Writing – original draft. WH: Writing – original draft. HL: Writing – review and editing. HB: Writing – original draft. JW: Writing – original draft. XL: Writing – review and editing. WL: Writing – review and editing. KL: Writing – review and editing.

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Conflict of interest

Authors CZ, YL, HL, and JW were employed by Pipe China West Pipeline Company. Author SL was employed by Pipe China North Pipeline Company. Author WH was employed by Pipe China Gansu Pipeline Company. Author HB was employed by Shanxi Oil and Gas Transmission Branch of Pipe China Northwest Pipeline Company.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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