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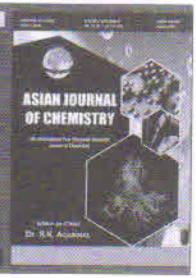

REVIEW

Sustainable Polymer–Nanoparticle Nanocomposites: A Comparative Review of PMMA, PLA, PVA and Chitosan Systems

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The rising demand for eco-friendly, high-performance materials has accelerated interest in polymer–nanoparticle nanocomposites (PNNCs) as sustainable alternatives to conventional plastics. This review presents an integrated comparison of PNNCs based on polymethyl methacrylate (PMMA), polylactic acid (PLA), polyvinyl alcohol (PVA) and chitosan matrices reinforced with inorganic nanoparticles such as TiO_2, ZnO, Ag, hydroxyapatite (HA) and Fe_3O_4. Nanofiller incorporation typically enhances the tensile strength by 20-60%, thermal stability by 10-25°C and antimicrobial efficiency up to >99% reduction in bacterial load, depending on matrix–nanoparticle compatibility. For example, PLA–HA nanocomposites show up to 40% improvement in modulus and accelerated bioactivity for orthopaedic applications, whereas PMMA–TiO_2 composites maintain optical clarity while providing enhanced UV-shielding and scratch resistance. A sustainability framework is applied to compare biodegradability and recyclability, highlighting PLA and chitosan as circular-economy-aligned matrices, while PMMA and PVA require responsible end-of-life strategies. Emphasis is placed on green synthesis routes, nanoparticle leaching behaviour and life-cycle considerations including environmental exposure risks. Challenges such as achieving stable nanoparticles dispersion, tuning interfacial chemistry and minimizing ecotoxicity are critically evaluated. The novelty of this work lies in bridging functional performance with life-cycle sustainability, directly aligning PNNC design principles with relevant UN Sustainable Development Goals.

Keywords: Sustainable nanocomposites, Biodegradable polymers, Green synthesis, Circular economy, Chitosan.