Multifunctional Biopolymer Blends: Tailoring PLA/PCL Composites for Advanced Applications

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This study presents an in-depth investigation of polylactic acid (PLA) and polycaprolactone (PCL) blends, aiming to optimize their structural and functional properties for sustainable and smart material applications. The research integrates advanced rheological, thermal, and mechanical characterization techniques to evaluate phase separation behavior and viscoelastic performance. Polymer blends with varying PLA/PCL ratios were prepared via melt extrusion — a scalable and eco-friendly processing method [1]. Scanning electron microscopy (SEM) revealed morphology transitions from droplet–matrix to co-continuous and phase-inverted structures as the PCL content increased. Rheological measurements highlighted composition-dependent shear-thinning behavior and complex moduli indicative of phase interactions. DMTA analysis showed significant influence of PCL content on the glass transition temperature and mechanical moduli, reflecting changes in thermal and elastic behavior. Differential scanning calorimetry (DSC) confirmed suppressed PLA crystallization and enhanced PCL crystallinity in the blends. Thermogravimetric analysis (TGA) demonstrated that even small additions of PCL significantly improve the thermal stability of PLA. The presence of two distinct degradation stages further confirmed phase separation in immiscible blends. Cole–Cole plots and phase angle analysis offered deeper insight into interfacial dynamics and phase morphology. The combination of these findings highlights the tunable nature of PLA/PCL systems through compositional control. This work bridges current gaps in understanding multiphase biopolymer systems by integrating diverse analytical approaches. The resulting materials exhibit properties ideal for additive manufacturing, shape memory behavior, and other advanced applications. Overall, the study contributes valuable knowledge for designing environmentally friendly, high-performance polymer blends.

Keywords: biopolymer blends, phase separation, rheological characterization, thermal analysis

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References

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