Chapter 6
Sustainable Bio-Based Nanocomposites:
Engineering Regenerable Materials for Tomorrow

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ABSTRACT

Bio-based nanocomposites represent a transformative frontier in materials science, offering sustainable alternatives to conventional petroleum-derived composites. This chapter examines sustainable bio-based nanocomposites with emphasis on their regenerability across multiple life cycles. Beginning with fundamental principles governing synthesis and structure-property relationships, the work explores interactions between bio-based matrices and nanoscale reinforcements. Processing techniques balancing performance with sustainability are analyzed, establishing foundations for understanding degradation mechanisms and regeneration strategies. Both chemical and physical aging processes are investigated, connecting these insights

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to effective regeneration approaches. The chapter addresses lifecycle assessment through environmental impact evaluations spanning multiple regeneration cycles. Advanced characterization techniques and economic considerations are discussed alongside emerging trends, serving as a foundational resource and catalyst for future innovations in sustainable materials.

1. INTRODUCTION

The emergence of bio-based nanocomposites marks a pivotal transformation in materials science and engineering, representing a fundamental shift toward developing truly sustainable material alternatives that address the growing environmental imperatives of the 21st century (Thomas et al., 2022). In an era where environmental concerns and resource scarcity increasingly influence scientific inquiry and industrial practices, these advanced materials offer promising pathways toward addressing the complex challenges of sustainability while maintaining the demanding performance requirements of modern technological applications (Thakur, 2023).

1.1 Scope and Significance of the Work

This chapter aims to provide a comprehensive examination of sustainable bio-based nanocomposites with specific focus on their regenerability characteristics and circular economy integration. The scope encompasses fundamental scientific principles underlying material behavior, advanced processing methodologies enabling sustainable manufacturing, comprehensive performance characteristics across multiple application domains, systematic environmental impact assessment throughout complete lifecycles, and detailed economic considerations spanning initial development through commercial implementation (Gopi et al., 2023).

The work specifically addresses materials comprising nanoscale reinforcements embedded within matrices derived from renewable biological sources, with particular emphasis on systems designed for multiple functional lifecycles through controlled regeneration processes. This includes natural polymer matrices such as cellulose, starch, and protein-based systems, bio-derived synthetic polymers including polylactic acid (PLA) and polyhydroxyalkanoates (PHAs), and various nanoscale reinforcements ranging from cellulose nanocrystals to bio-derived carbon nanomaterials (Klemm et al., 2023).

The significance of this research lies in its potential to address critical global challenges including plastic pollution, resource depletion, climate change mitigation, and the urgent need for circular economy implementation. With global plastic production exceeding 380 million tonnes annually and less than 10% being effectively

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