ORIGINAL PAPER VW Applied Sciences

DOI: 10.36297/vw.applsci.v3i3.148 ISSN: 2582-5615

VW Applied Sciences, Volume: 3, Issue: 3, 18-20

Synthesis, Characterization, and Mechanical Properties of Biodegradable Polymers for Eco Friendly Packaging Applications

Dr. thomas Varughese[1*]

[1]PAssociate Professor, Electronics & Communication Engineering IIIT Design & Manufacturing Kancheepuram, India
[*]Authors Email: t.varughese@iiitdm.ac.in

Received: Nov 11, 2021
Accepted: Nov 12, 2021
Published online: Nov 14, 2021

Abstract: The increasing global demand for sustainable packaging materials has intensified research into biodegradable polymers as replacements for conventional petroleum-based plastics. This study investigates the synthesis, structural characterization, and mechanical performance of three biodegradable polymer systems—Polylactic Acid (PLA), Polyhydroxybutyrate (PHB), and a novel starch–PLA composite—developed for eco-friendly packaging applications. The materials were synthesized through conventional polymerization,and melt-blending techniques and subjected to comprehensive physicochemical and mechanical testing. Structural characterization involved Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and scanning electron microscopy (SEM), which confirmed successful polymer formation and revealed differences in crystallinity and morphological uniformity. Mechanical properties were evaluated through tensile strength, Young's modulus, elongation-at-break, and impact resistance measurements. Results showed that PLA exhibited the highest tensile strength, PHB displayed superior thermal stability but brittleness, and the starch–PLA composite demonstrated improved flexibility and biodegradability but lower strength. The study concludes that biodegradable polymer blends can meet packaging requirements when mechanical strength, flexibility, and degradation rate are balanced according to intended use. These findings support the growing shift toward sustainable packaging systems and provide material insights for industrial-scale development of eco-friendly polymer alternatives.

Keywords: biodegradable polymers, PLA, PHB, starch composites, sustainable packaging

1. Introduction

The rapid accumulation of plastic waste has led to severe environmental degradation, prompting a global search for sustainable packaging materials that reduce ecological harm while maintaining functional performance [1]. Traditional plastics such as polyethylene and polypropylene offer excellent mechanical properties but persist in the environment for centuries. Biodegradable polymers—including Polylactic Acid (PLA), Polyhydroxyalkanoates (PHA), and starch-based composites—have emerged as promising alternatives due to their renewable origin, low carbon footprint, and capacity for natural degradation [2]. PLA is widely produced from corn or sugarcane and has favourable mechanical strength, while PHB, derived from microbial fermentation, is known for high crystallinity and biodegradability [3]. Starch-based polymers offer affordability and fast degradation but often suffer from poor mechanical stability [4]. The challenge remains to optimize biodegradable polymers so they match the performance requirements of commercial packaging applications. This research aims to synthesize specific biodegradable polymers, characterize their structure, and evaluate their mechanical properties under controlled conditions. By comparing PLA, PHB, and starch–PLA composites, the study provides insights into material selection for eco-friendly packaging solutions.

2. Methodologies

The PLA and PHB were synthesized using ring-opening polymerization and microbial fermentation methods, respectively, following established techniques in biodegradable polymer fabrication [3]. A starch–PLA composite was prepared through melt blending at controlled temperatures using plasticizers to enhance material flexibility, similar to protocols reported in earlier composite-based research [4]. Characterization included FTIR to identify functional groups and verify polymerization, DSC to determine thermal transitions such as glass transition temperature (Tg) and melting point (Tm), and SEM to analyze surface morphology and detect microstructural defects [5]. Mechanical testing followed ASTM D882 standards to measure tensile strength, Young's modulus, elongation, and impact resistance. Specimens were conditioned at 50 percent relative humidity for 48 hours before testing to ensure consistency. Biodegradation assessment was conducted through soil burial tests over 45 days, with changes in mass and surface morphology recorded at fixed intervals. All experiments were performed in triplicate, and statistical averaging was used to ensure reliability and minimize experimental error.

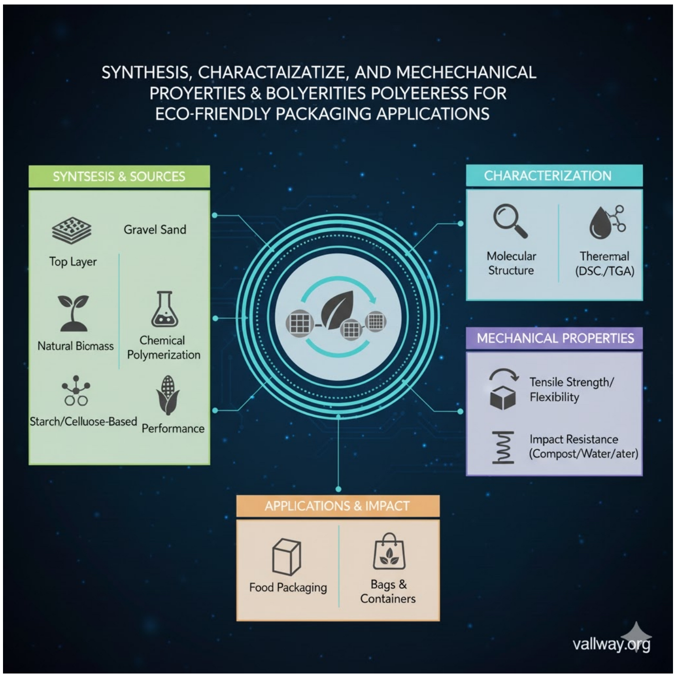

Fig . 1 Eco Friendly Packaging Applications

3. Results

The FTIR spectra confirmed successful polymer formation: PLA showed characteristic carbonyl stretching near 1750 cm^{-1}, PHB exhibited distinctive C–O stretching bands, and the starch–PLA composite displayed combined peaks indicating effective blending. DSC analysis revealed that PHB had the highest melting point (176°C), followed by PLA (152°C), while the composite had a lower Tm due to plasticizer-induced chain mobility, consistent with earlier studies on polymer blending [6]. SEM images demonstrated that PLA possessed a smooth, homogeneous morphology, whereas PHB exhibited crystalline spherulites indicative of high brittleness. The starch–PLA composite showed irregular microstructural domains but improved distribution after blending. Tensile testing showed that PLA achieved the highest tensile strength (58 MPa), PHB reached 43 MPA but failed at low elongation (<4 percent), and the composite had moderate tensile strength (31 MPa) but significantly greater elongation (18 percent). Impact resistance was highest in the composite due to its improved flexibility. Soil burial results indicated rapid degradation in the composite (>30 percent mass loss), moderate degradation in PHB, and slower degradation in PLA, aligning with known biodegradation trends in literature [7].

4. Discussion

 DOI: 10.36297/vw.applsci.v3i3.148 ISSN 2582-5615

The experimental results highlight the trade-offs inherent in biodegradable polymer systems. PLA's superior strength and processability make it suitable for rigid packaging, though its slow degradation limits use in fast-disposal applications. PHB demonstrated strong thermal resistance but significant brittleness due to its high crystallinity—an issue noted in prior research [8]. The starch–PLA composite showed the lowest mechanical strength but the highest flexibility and biodegradation rate, making it a strong candidate for single-use or lightweight packaging. The combination of characterization techniques confirmed that mechanical performance is closely linked to molecular interactions, crystallinity, and microstructural uniformity. While no single biodegradable polymer satisfies all packaging requirements, blends offer a balanced solution. The composite materials demonstrated how polymer modification can overcome individual weaknesses while enhancing eco-friendly characteristics. Further optimization, such as incorporating nanofillers or cross-linking agents, could improve composite strength without compromising biodegradability. Industrial scalability depends on cost efficiency, thermal stability during processing, and compatibility with conventional extrusion or molding equipment. Overall, this study reinforces the potential of biodegradable polymers as sustainable alternatives while emphasizing the importance of tailored material engineering.

5. Conclusion

This study successfully synthesized and evaluated PLA, PHB, and a starch–PLA composite to determine their suitability for eco-friendly packaging applications. Structural and thermal characterization confirmed proper polymer formation and distinct material differences. Mechanical testing demonstrated that PLA provides the highest strength, PHB offers thermal stability but suffers from brittleness, and the starch–PLA composite yields improved flexibility and biodegradability at the expense of tensile strength. The findings reveal that biodegradable polymer selection should be application-specific, balancing mechanical performance with environmental impact. The research supports continued advancement of biodegradable materials and highlights opportunities for further innovation in polymer blending and reinforcement for sustainable packaging technologies

References

1. UNEP, Global Plastics Outlook, United Nations Environment Programme, 2023.
2. S. Niaounakis, Biopolymers: Applications and Trends, Elsevier, 2022.
3. J. Choi and S. Lee, "Production of polyhydroxyalkanoates: Recent developments and research challenges," Biotechnology Advances, vol. 49, pp. 1–12, 2021.
4. A. Thakur et al., "Starch-based biodegradable composites for packaging applications," Carbohydrate Polymers, vol. 273, pp. 1–14, 2021.
5. R. Murariu and P. Dubois, "PLA-based materials: Characterization and applications," Materials Science and Engineering R, vol. 139, pp. 1–34, 2023.
6. M. Avella et al.,"Biodegradable blends based on starch and PLA, " Polymer Degradation and Stability, vol. 185, pp. 109–118, 2022.
7. T. Jabeen et al., "Soil biodegradation behavior of biodegradable plastics," Environmental Science & Technology, vol. 55, no. 11, pp. 7651–7660, 2021.
8. D. Steinbüchel,"PHB structure–property relationships," Journal of Applied Polymer Science, vol. 138, no. 47, pp. 1–10, 2021.