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Synthesis, Mechanical Testing, and Biodegradability Assessment of Polymers for Engineering Packaging Applications

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Abstract: The increasing environmental burden of petroleum-based plastic packaging has intensified research into biodegradable polymeric materials capable of meeting mechanical and functional requirements of engineering applications. Conventional plastics exhibit excellent strength and durability but persist in the environment for decades, contributing to pollution and ecological degradation. This study presents the synthesis, mechanical characterization, and biodegradability assessment of biodegradable polymer composites developed for engineering packaging applications. Polylactic acid (PLA) and starch-based polymer blends were synthesized using melt blending techniques, with natural fiber reinforcements incorporated to enhance mechanical performance. Standardized mechanical tests, including tensile, flexural, and impact strength evaluations, were conducted to assess material suitability for load-bearing and protective packaging. Biodegradability was examined through controlled soil burial and composting experiments, monitoring mass loss and structural degradation over time. Results demonstrate that optimized polymer blends achieve mechanical properties comparable to conventional packaging plastics while exhibiting significantly enhanced biodegradation rates. The findings highlight the potential of biodegradable polymer systems as sustainable alternatives for engineering packaging applications.

Keywords: Biodegradable Polymers, Sustainable Packaging, Mechanical Properties, Polymer Composites, Environmental Degradation

1. Introduction

Packaging materials play a critical role in protecting goods during storage, transportation, and distribution. Engineering packaging applications demand materials that provide mechanical integrity, impact resistance, and dimensional stability under variable environmental conditions. Traditionally, petroleum-derived polymers such as polyethylene and polypropylene have dominated packaging industries due to their low cost and favorable mechanical properties. However, their resistance to biodegradation has resulted in severe environmental consequences, including landfill accumulation and marine pollution [1]. Biodegradable polymers offer a promising solution by combining functional performance with environmental compatibility. Polymers derived from renewable resources, such as polylactic acid and starch-based materials, have gained attention due to their reduced carbon footprint and inherent biodegradability. Nevertheless, limitations in mechanical strength and moisture resistance restrict their widespread adoption in engineering-grade packaging. This research focuses on overcoming these limitations through polymer blending and reinforcement strategies.

2. Materials Selection and Polymer Synthesis

Polylactic acid was selected as the primary biodegradable polymer matrix due to its availability, processability, and favorable mechanical properties. Thermoplastic starch was incorporated to enhance biodegradability and reduce material cost. Natural fiber reinforcement derived from jute was used to improve tensile and flexural

strength while maintaining sustainability. Polymer blends were synthesized using a twin-screw extruder operating at controlled temperature and shear conditions to ensure homogeneous mixing. The extruded strands were pelletized and compression molded into standardized test specimens. Glycerol was added as a plasticizer to improve flexibility and reduce brittleness associated with PLA-based materials [2].

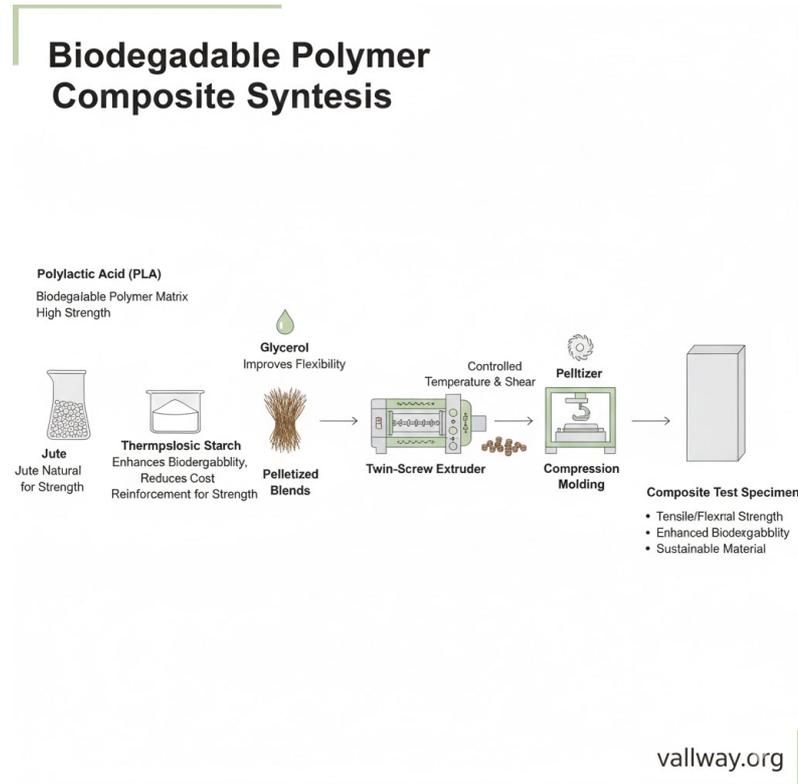


Fig. 1

3. Mechanical Testing Methodology

Mechanical characterization was performed according to ASTM standards to evaluate material performance for packaging applications. Tensile testing was conducted using a universal testing machine to determine tensile strength, Young's modulus, and elongation at break. Flexural strength and modulus were measured through three-point bending tests, while impact resistance was assessed using the Izod impact test. The influence of fiber content and polymer blend ratio on mechanical properties was systematically analyzed. Results were compared with conventional packaging plastics to establish performance benchmarks.

4. Biodegradability Assessment Techniques

Biodegradability was evaluated through soil burial and composting experiments conducted over a 12-week period. Test specimens were buried in controlled soil environments with regulated moisture and temperature conditions. Periodic retrieval allowed measurement of mass loss, surface morphology changes, and mechanical property degradation [3]. Scanning electron microscopy was employed to observe microstructural changes resulting from microbial activity. Composting tests were performed to simulate industrial biodegradation conditions and assess accelerated degradation behavior.

5. Results and Analysis

Mechanical testing results revealed that PLA–starch blends reinforced with natural fibers exhibited significant improvements in tensile and flexural strength compared to unreinforced blends. Optimized formulations achieved tensile strength values within 80–90% of conventional polyethylene packaging materials. Biodegradability studies indicated substantial mass loss, exceeding 40% after 12 weeks of soil burial, compared to negligible degradation observed in petroleum-based plastics. Fiber-reinforced composites showed slightly reduced degradation rates due to increased structural integrity but remained significantly more biodegradable than conventional polymers. The trade-off between mechanical strength and biodegradability highlights the importance of formulation optimization for application-specific requirements.

6. Packaging Performance Evaluation

In addition to mechanical strength, packaging performance parameters such as dimensional stability, moisture absorption, and surface integrity were evaluated. Although biodegradable polymers exhibited higher moisture sensitivity, surface coatings and barrier layers showed potential for mitigating this limitation. Drop and compression tests demonstrated adequate protective performance for secondary packaging applications, indicating suitability for engineering logistics and industrial packaging.

7. Environmental and Industrial Implications

The use of biodegradable polymer composites reduces dependence on fossil resources and minimizes long-term environmental pollution. Life-cycle assessment studies indicate lower greenhouse gas emissions compared to conventional plastics, particularly when renewable feedstocks are used [4]. From an industrial perspective, compatibility with existing polymer processing equipment enhances scalability and commercial feasibility. Cost reductions are achievable through material optimization and increased production volumes.

8. Conclusion

This study demonstrates the feasibility of biodegradable polymer composites for engineering packaging applications through systematic synthesis, mechanical testing, and biodegradability assessment. The developed materials exhibit competitive mechanical properties while offering significant environmental advantages. Continued research into moisture resistance and large-scale processing will further enhance their industrial applicability.

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