Packaging materials, Medical materials, Environmentally degradable materials

High-performance sequence-controlled PLA bioplastics with adjustable marine biodegradability

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Abstract

The development of high-performance biodegradable plastics is crucial to address the growing global plastic pollution, particularly in marine environments. PLA is a promising alternative to petroleum-based plastics due to its biodegradability, biocompatibility, and mechanical properties, but its durability in water is limited, restricting its long-term use in aquatic environments. In this study, novel PEG–PLA multiblock copolymers were synthesized with precise control of molecular sequence and block architecture to achieve an optimal balance between water resistance and marine biodegradability. The introduction of PEG significantly increased surface hydrophilicity, reducing the water contact angle from 80.9° to 38.3°, and improving water absorption. SEM observations confirmed structural stability after long-term water immersion. Thermal-mechanical characterization revealed enhanced flexibility due to the lowered glass transition temperature, while XRD analysis showed PEG-induced α-phase crystallization, improving crystallinity and mechanical strength. Tensile tests demonstrated that alternating block structures maintained high stretchability and toughness under wet conditions. Enzymatic hydrolysis and seawater biodegradation tests indicated that random structures with short PLA segments degraded rapidly, with PEG4kPLA2k-r achieving a 72.63% degradation rate. These results demonstrate that PEG–PLA copolymers provide tunable properties, balancing durability and rapid biodegradation, making them promising candidates for sustainable applications in packaging, agriculture, and medical devices.

Background & Results

Plastic pollution is a serious environmental issue, particularly in oceans where accumulated waste threatens marine ecosystems. Developing renewable, biodegradable, and high-performance plastics is critical. PLA is widely recognized for its biodegradability, biocompatibility, and mechanical properties, but it exhibits insufficient water durability for long-term marine use. In this research, PEG–PLA multiblock copolymers were synthesized with controlled sequence and block structures to overcome these limitations. PEG incorporation enhanced hydrophilicity, reducing the water contact angle from 80.9° to 38.3° and improving water absorption. SEM analysis confirmed that the structure remained intact after prolonged water immersion. Thermal-mechanical tests showed that the glass transition temperature decreased, increasing flexibility. XRD revealed α-phase crystallization induced by PEG, leading to higher crystallinity and improved mechanical strength. Alternating block structures exhibited excellent tensile strength and toughness in wet conditions. Enzymatic and seawater biodegradation tests demonstrated that random structures with short PLA segments degraded rapidly, achieving over 70% degradation in a short period. These improvements are attributed to enhanced hydrophilicity, disrupted crystallinity, and structural irregularities that facilitate enzyme access and water diffusion. Overall, the study demonstrates that PEG–PLA copolymers can simultaneously achieve water durability and rapid marine biodegradation, providing a new platform for designing environmentally friendly plastics.

Significance of the research and Future perspective

This research highlights the potential of PEG–PLA copolymers as environmentally sustainable materials that address the dual challenge of durability and biodegradability. The ability to tune properties through molecular design allows control over degradation rates and mechanical performance, offering opportunities for packaging, agricultural films, and medical device applications. The results guide the development of plastics that degrade efficiently in marine environments while retaining functional performance during use. Future work could explore varying block lengths, sequence patterns, and copolymer compositions to further optimize mechanical and degradation properties, broadening the range of applications. By integrating precise molecular design and functional performance, this study contributes to reducing marine plastic pollution and advancing sustainable material solutions, supporting the transition toward a circular and environmentally responsible society.

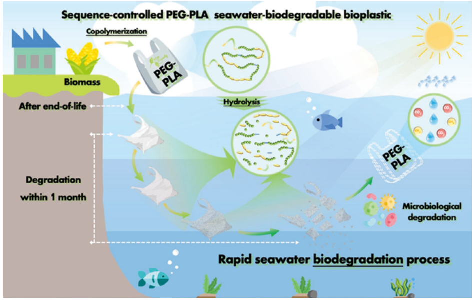

Figure 1.

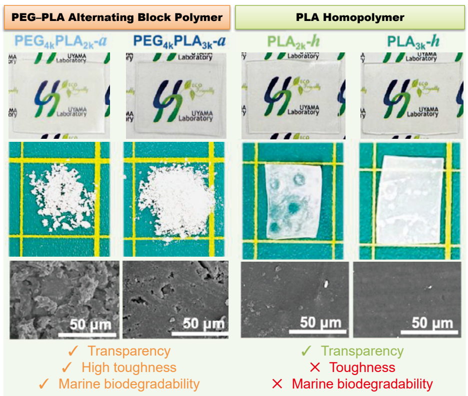

Figure 2.

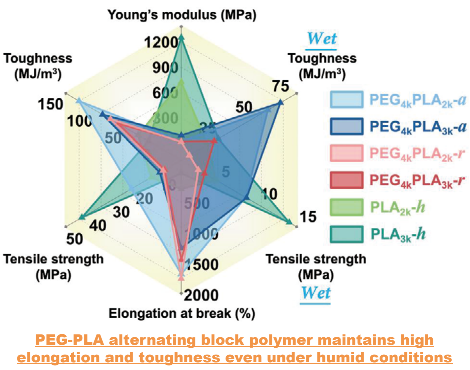

Figure 3.

Patent

Treatise He, Manjie; Hsu, Yu-I; Uyama, Hiroshi. Superior sequence-controlled poly(L-lactide)-based bioplastic with tunable seawater biodegradation. Journal of Hazardous Materials. 2024, 474, 134819. doi: 10.1016/j.jhazmat.2024.134819

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Keyword PLA-based bioplastics, tunable seawater biodegradability, degradation mechanism, BOD analysis