Functionalization of Polymer Materials Based on Lignin Backbones for Resource Circulation

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The development of polymer materials compatible with resource circulation is essential for achieving a sustainable society, particularly in light of the increasing demand for high-performance materials with controlled end-of-life behavior. Conventional polymer systems often exhibit either excellent durability or degradability, but rarely both, creating a fundamental challenge in materials design[1]. In this study, polymer materials based on lignin backbones were designed from two complementary perspectives: photothermal functionality and chemically controlled degradability, aiming to integrate performance during use with efficient deconstruction after use (Figure 1).

First, a photothermal adhesive system was developed by incorporating lignin into a polyester-based hot-melt adhesive, exploiting its intrinsic ability to convert absorbed light into heat. Upon near-infrared (NIR) irradiation, the lignin-containing adhesive exhibited a rapid and significant temperature increase, enabling efficient debonding through thermal softening. In contrast to the pristine adhesive, the lignin composites not only retained but also enhanced adhesion strength, while allowing on-demand dismantling triggered by external stimuli. This simple material design demonstrates a practical strategy for reversible bonding without complex chemical modification.

Second, a degradable polymer system was designed by introducing lignin-inspired structural motifs into aromatic polyethers. Specifically, benzil and hydrobenzoin units, which mimic the β-1 linkage found in lignin, were incorporated into the polymer backbone. Under oxidative conditions, these polymers underwent selective bond cleavage, as confirmed by spectroscopic analysis, resulting in the formation of lower-molecular-weight species. The degradation behavior is attributed to the cleavage of diketone and diol structures, providing a controllable pathway for polymer decomposition.

Overall, this study demonstrates that lignin-derived structural and functional features can be effectively leveraged to construct polymer systems that combine mechanical robustness, stimulus responsiveness, and controlled degradability. The integration of photothermal debonding and chemically triggered degradation offers a versatile platform for designing sustainable polymer materials. This work provides a molecular-level design strategy toward advanced materials that bridge the gap between durability in service and degradability after use, contributing to the realization of circular material systems.

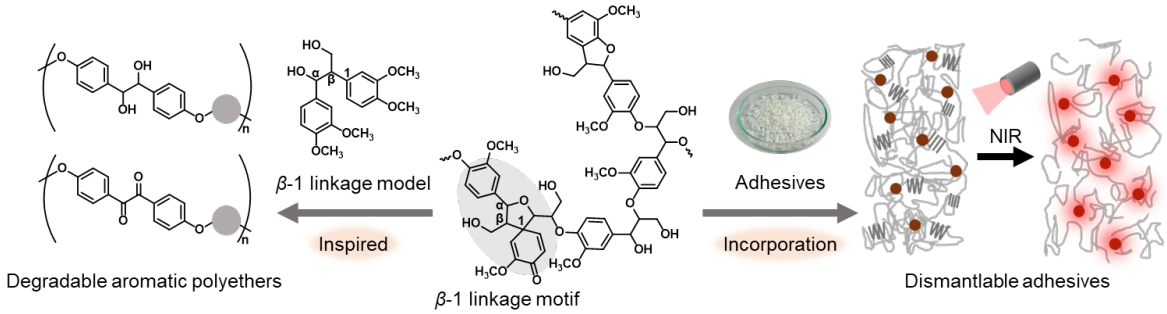

Figure 1. Lignin-based polymer materials for controlled deconstruction.

References 1. J. Lei *et al., Adv. Sci.* **2025**, *12*, 2501259.

Biography (For Plenary, Keynote, and Invited Speakers)

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Personal History:
Akihide Sugawara received his Ph.D. in Engineering from the Department of Applied Chemistry, Graduate School of Engineering, Osaka University, in March 2022. He subsequently worked as a specially appointed researcher at Osaka University and has been serving as an Assistant Professor in the same department since May 2022.
His research focuses on the molecular design of functional polymer materials, particularly hydrogels and cellulose-based systems. He is interested in constructing advanced polymer networks through tailored intermolecular interactions and dynamic covalent chemistry, aiming to integrate structural robustness with stimuli-responsive and reversible behaviors. His recent work includes the development of mechano-responsive hydrogels utilizing supramolecular host–guest interactions as molecular switches, as well as bio-based polymer networks derived from cellulose for sustainable material applications.

Research Keyword (3-5 keywords use commas to separate each word):
Polymer Materials, Plastics, Hydrogels