High-Resolution Additive Manufacturing of High Lignin-Content Biocomposites

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Introduction

Vat photopolymerization additive manufacturing relies heavily on petrochemical-based resins, raising sustainability concerns. Lignin, an abundant industrial byproduct, offers a renewable alternative; however, its strong UV absorption limits its application. Previous efforts were restricted to low-resolution, 2.5D structures with lignin content rarely exceeding 15 wt.% and feature sizes around 1 mm[1]. This study addresses these challenges by developing Digital Light Processing (DLP) resins containing up to 40 wt.% lignin[2]. UV absorption is reduced by 71 % through a low-energy decolorization process. The modified lignin is incorporated into bio-based tetrahydrofurfuryl acrylate, enabling high-resolution additive manufacturing with a resolution of 250 µm. Lignin's reinforcing effect enhances the material's stiffness (15×) and strength (2.3×). This approach advances the sustainability of high-resolution additive manufacturing through the efficient valorization of lignin.

I. Decolorization of Lignin

Lignin's strong UV absorption hinders photoinitiator activation, limiting its role as a sustainable filler in vat photopolymerization. This challenge is addressed by decolorizing organosolv lignin (OSL) via an optimized, low-energy process combining acetylation and UV irradiation, achieving a 71 % reduction in UV absorption.

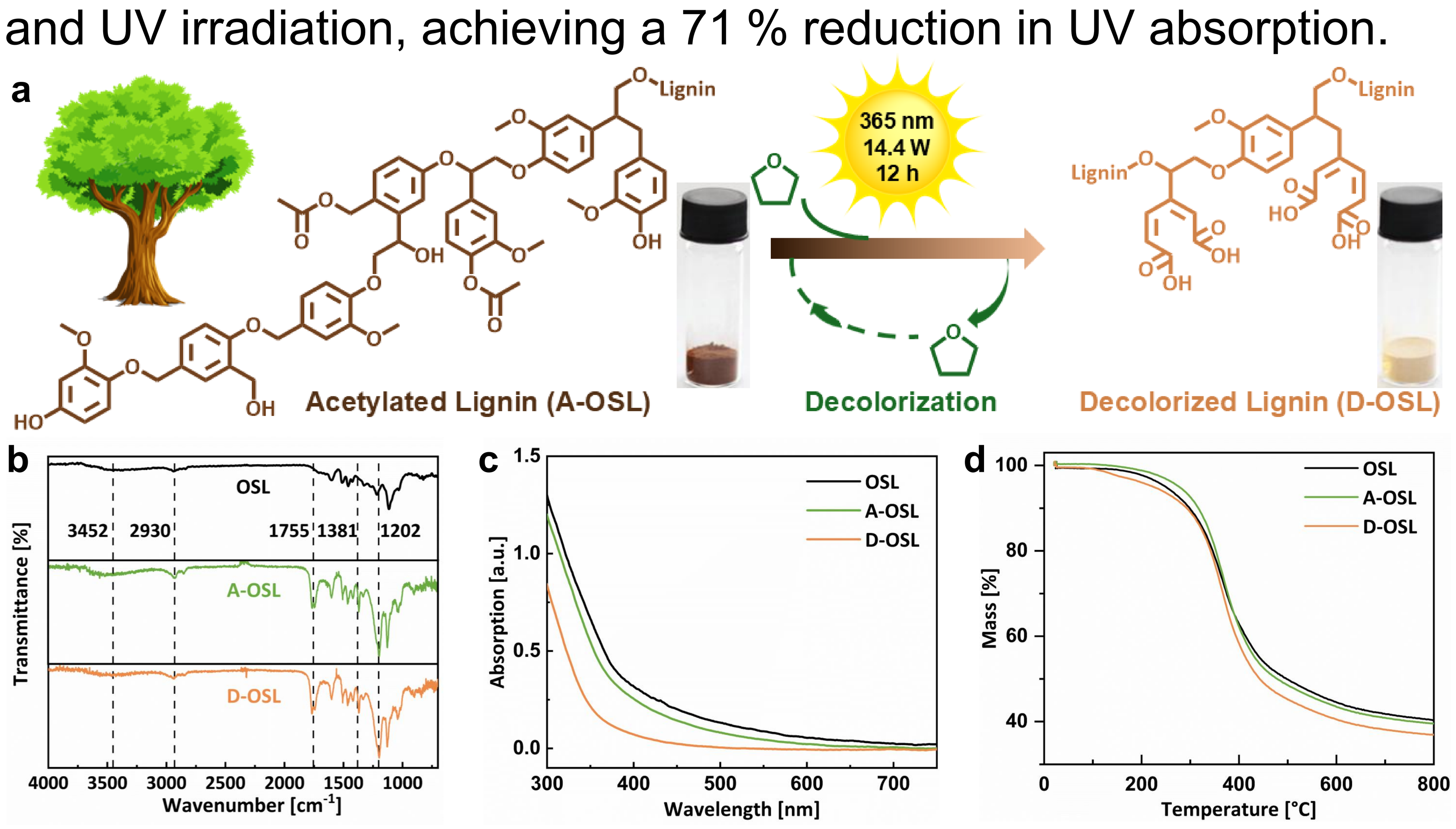

Figure 1. Decolorization of lignin via UV irradiation. a) Schematic of energy-efficient lignin decolorization in recyclable THF for high-lignin resin development, aligned with the project goals. b) FTIR confirms successful acetylation of A-OSL. The absence of changes in characteristic bands after irradiation indicates no significant degradation. c) UV-Vis shows ~71% reduction in absorption at 385 nm for D-OSL vs. A-OSL and OSL. d) TGA indicates similar thermal stability before and after irradiation, supporting structural preservation.

II. Development of Photo-Induced Resin

Sustainable resins for high-resolution additive manufacturing were developed by incorporating up to 40 wt.% fully dissolved decolorized organosolv lignin into tetrahydrofurfuryl acrylate (THFA), a low-viscosity, bio-based monofunctional acrylate.

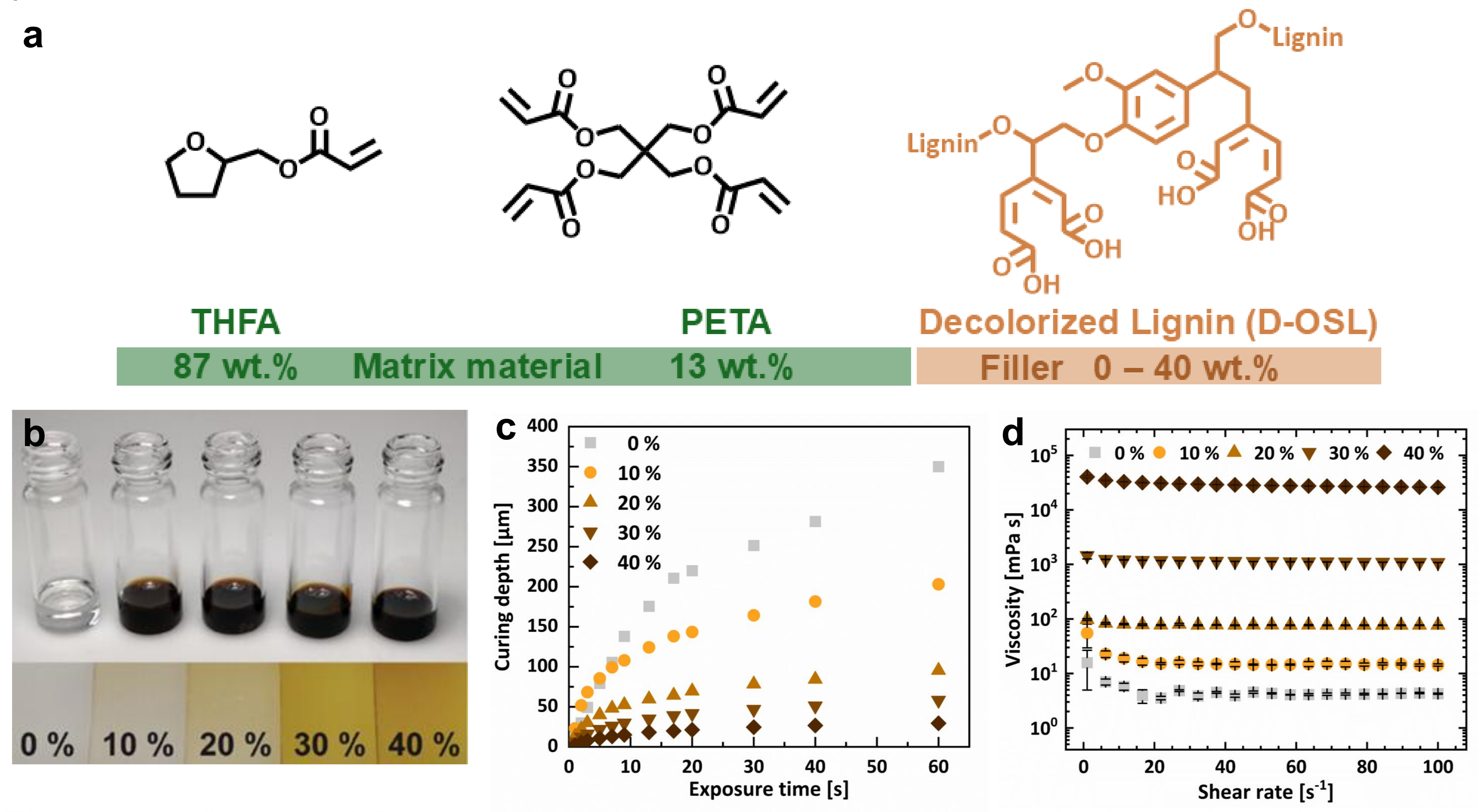

Figure 2. Composition, optical property, reactivity, and viscosity of achieved resins. a) Resin formulation with bio-based THFA (matrix), PETA (crosslinker), and D-OSL (bio-based filler). b) Optical appearance of resins with D-OSL content from 0 wt.% to 40 wt.%, shown in vials and as 40 µm films. c) Resin reactivity shown via calibration curves. d) Shear rate-dependent viscosity profiles.

III. High-Lignin Additive Manufacturing

High-resolution, complex 3D structures were fabricated using the developed high lignin-content resins via DLP.

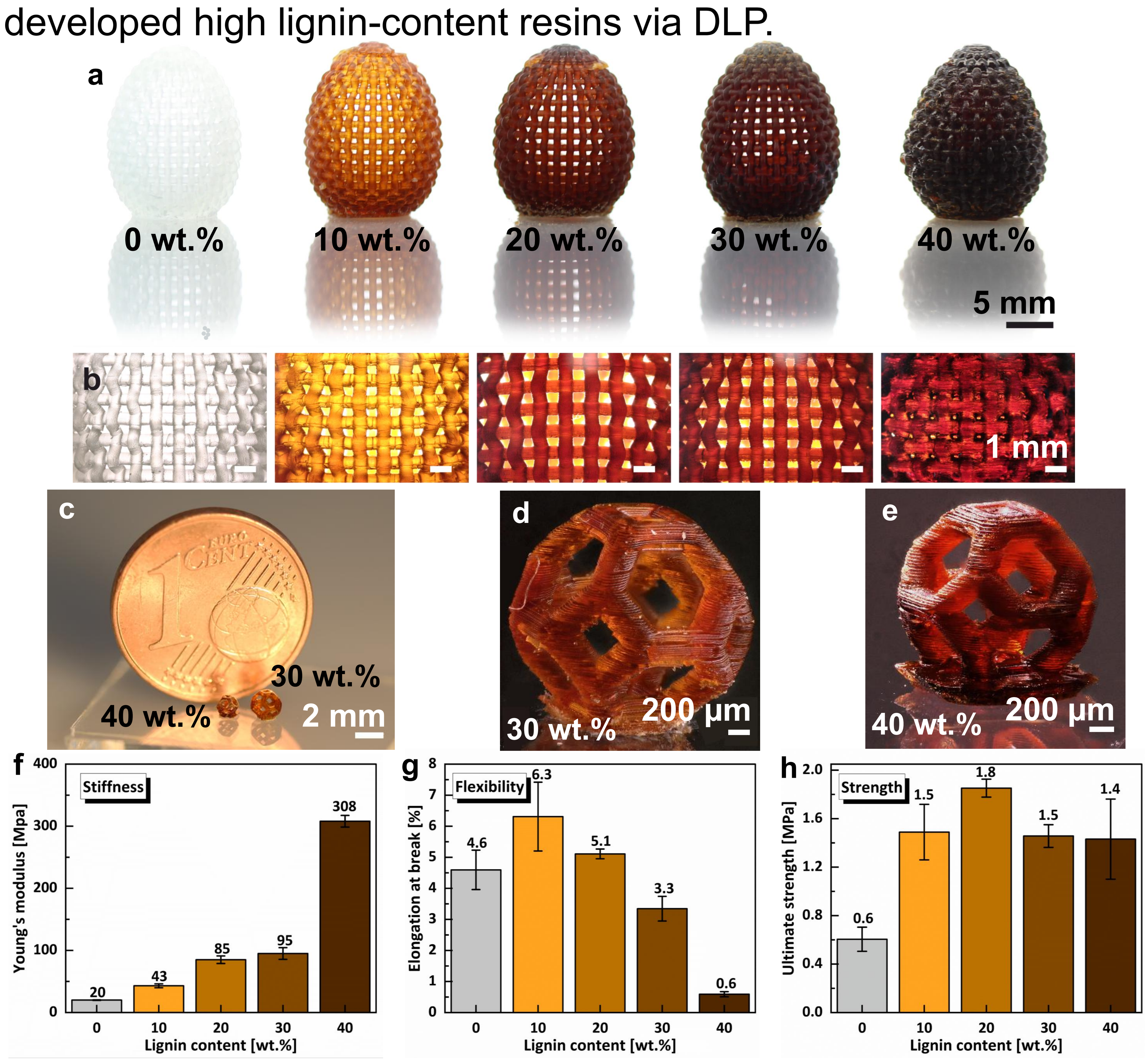

Figure 3. DLP 3D-printed structures and mechanical properties of lignin composites. a) Lattice eggs with up to 40 wt.% decolorized lignin (D-OSL). b) Microscopy images showing fine lattice features. c) Truncated octahedrons with 30 wt.% and 40 wt.% D-OSL. d) Microscopy image showing line width of 300 µm for 30 wt.% D-OSL. e) Microscopy image showing line width of 250 µm for 40 wt.% D-OSL. f) Young's modulus, highlighting significantly increased stiffness due to lignin reinforcement. g) Strain at break, showing reduced flexibility at higher lignin content due to lignin's inherent rigidity. h) Ultimate stress, confirming lignin's strengthening effect.

Conclusion

High lignin-content resins with up to 40 wt.% lignin content were developed using a low-energy UV decolorization process, enabling high-resolution vat photopolymerization with feature sizes down to 250 µm. These biocomposites offer enhanced mechanical properties and improved sustainability, providing a promising route toward next-generation materials for high-resolution additive manufacturing.

References

[1] J. T. Sutton, et al., ACS Appl. Mater. Interfaces, 10, 36456–36463, **2018**.
[2] D. Böcherer, et al., Advanced Science, 11, 2406311, **2024**.

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