SUSTAINABLE TRANSPARENT WOOD BASED ON BIO-BASED ISOBORNYL ACRYLATE/METHACRYLATE MATRICES

A. Cabras[1], D. Nuvoli [1], D. Pugliese [2], M. Terzi [3], A. Mariani [1], G. Malucelli [4]

[1] Department of Chemical, Physical, Mathematical, and Natural Sciences, University of Sassari, Via Vienna 2, Sassari 07100, Italy
[2] Division of Applied Metrology and Engineering, National Institute of Metrological Research (INRiM), Torino 10135, Italy
[3] Division of Quantum Metrology and Nanotechnologies, National Institute of Metrological Research (INRiM), Torino 10135, Italy
[4] Dept. of Applied Science and Tecnology, Politecnico di Torino, Viale T. Michel 5, 15121, Alessandria, Italy
e-mail: giulio.malucelli@polito.it

Introduction

Transparent wood (TW) has recently emerged as one of the most promising bio-based structural and functional materials for sustainable technologies. It is obtained by combining a lignocellulosic scaffold with a transparent polymer matrix, generating a composite capable of retaining the mechanical advantages of wood while exhibiting remarkable optical properties. Compared with conventional transparent materials such as glass and petroleum-derived plastics, transparent wood offers lower environmental impact, reduced density, enhanced toughness, and improved thermal insulation performance. Consequently, TW has attracted considerable attention for applications ranging from energy-efficient buildings and smart windows to solar cells, optical devices, and thermal management systems [1-3].

The fabrication of transparent wood generally involves the removal or modification of lignin, which contains chromophoric groups responsible for light absorption. The resulting porous cellulose-rich template is subsequently impregnated with a polymer possessing a refractive index close to that of cellulose. This refractive index matching minimizes light scattering at internal interfaces and enables high optical transmittance. To date, most TW systems rely on epoxy resins or poly(methyl methacrylate) (PMMA), which provide excellent optical performance but are predominantly derived from fossil resources.

In the present work, transparent wood was fabricated using bio-based isobornyl-derived monomers, namely isobornyl acrylate (IBOA) and isobornyl methacrylate (IBOMA), obtained from renewable terpene feedstocks. These monomers offer a renewable carbon content approaching 75-80%, together with refractive indices compatible with cellulose. The objective of this study was to investigate the suitability of polyIBOA, polyIBOMA, and their copolymers as sustainable matrices for transparent wood, evaluating their optical, thermal, and morphological characteristics.

Results and discussion

TW specimens were prepared starting from 1 mm thick balsa veneers. After delignification through sodium chlorite treatment, the wood templates were infiltrated with IBOA, IBOMA, or mixtures of the two monomers containing different molar fractions. UV-induced polymerization generated the final wood-polymer composites.

The optical performance of transparent wood strongly depends on the refractive index matching between the polymer phase and the cellulose scaffold. Measurements performed on the synthesized polymers revealed refractive indices between 1.492 and 1.498, values sufficiently close to that of cellulose (1.5) to ensure efficient light transmission through the composite.

UV-Vis characterization demonstrated excellent optical properties for all formulations. The transmittance spectra showed a rapid increase above 350-400 nm, followed by a plateau in the visible region. The best optical performance was obtained for the poly(IBOA-co-IBOMA) 50/50 system, which achieved approximately 80% transmittance at 550 nm. Copolymer-based TWs consistently exhibited higher optical transmittance than the corresponding homopolymer systems, suggesting improved refractive index matching and more homogeneous infiltration of the wood microstructure. In addition to transparency, all samples exhibited significant haze values, ranging from approximately 59 to 86% (Figure 1). High haze is a desirable feature for applications such as diffusive glazing and photovoltaic devices because it enhances light scattering while maintaining overall transparency. Pure polyIBOA produced the highest haze values, whereas the copolymer formulations achieved a better balance between transparency and light diffusion. Particularly, the 50/50 copolymer combined the highest optical transmittance with substantially reduced haze, demonstrating the possibility of

tailoring the optical response through copolymer composition.
The effectiveness of UV curing was confirmed by FTIR spectroscopy. The characteristic C=C stretching vibration associated with the monomer double bond disappeared after polymerization, indicating a high degree of conversion and successful network formation within the wood scaffold.

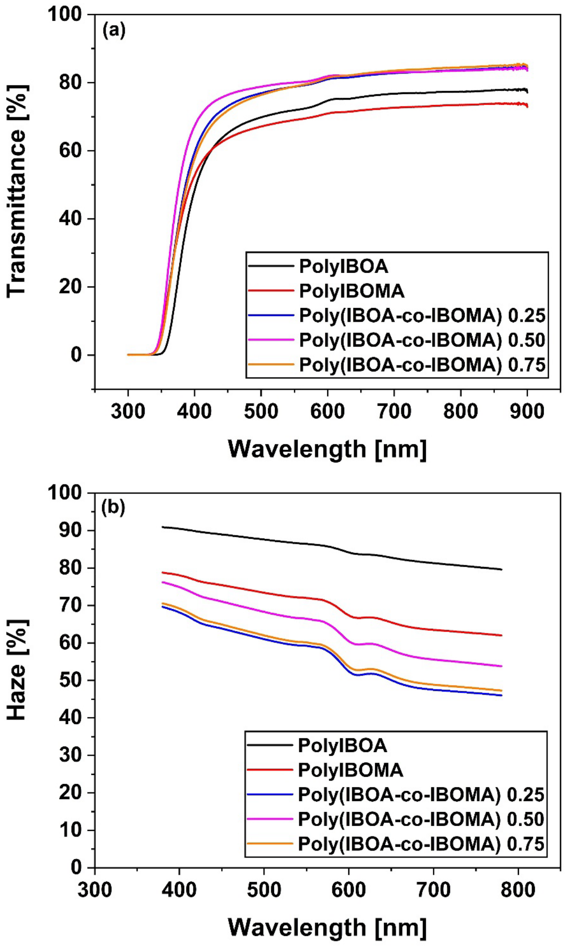

Figure 1. (a) optical transmittance and (b) haze as a function of wavelength for the investigated TW. In copolymers, the molar fraction of IBOA is indicated.

Morphological investigations by scanning electron microscopy revealed homogeneous filling of the wood lumina and intimate interaction between the polymer matrix and the cellulose framework. No significant voids or defects were observed, indicating efficient impregnation of both homopolymers and copolymers while preserving the intrinsic cellular architecture of the wood template.
Thermal conductivity measurements yielded values between 0.15 and 0.18 W m^{-1} K^{-1} for all investigated formulations. These values are consistent with those reported for advanced transparent wood systems and significantly lower than those of conventional glass. The limited variation among formulations suggests that thermal transport is mainly governed by the composite architecture rather than by the precise chemical composition of the polymer phase. Such low thermal conductivity highlights the potential of these materials for energy-saving building applications and thermally insulating transparent structures. Overall, the results indicate that bio-based isobornyl polymers provide an attractive combination of optical transparency, light diffusion, thermal insulation, and sustainability. The use of renewable terpene-derived monomers represents a significant step toward reducing the environmental footprint of transparent wood while maintaining competitive functional performance.

Conclusions

Transparent wood composites based on bio-derived polyIBOA, polyIBOMA, and their copolymers were successfully fabricated through delignification and UV-assisted polymer infiltration. The developed materials exhibited refractive indices compatible with cellulose, optical transmittance up to 80%, high haze values, homogeneous microstructures, and low thermal conductivity. Among the investigated systems, the poly(IBOA-co-IBOMA) 50/50 formulation provided the best balance between transparency and light diffusion. These findings demonstrate that isobornyl-based polymers constitute promising sustainable alternatives to conventional fossil-derived matrices for transparent wood production, opening new opportunities for environmentally friendly optical and structural materials.

References

[1] C. Chen et al., *Nat. Rev. Mater.*, vol. 5 642–666 (2020)
[2] G. Malucelli et al., *Nat. Rev. Mater.* (2026) 10.1038/s41578-026-00901-x
[3] A. Mariani and G. Malucelli, *Next Mater.*, vol. 5 5, 100255 (2024)

Acknowledgments

The authors gratefully acknowledge financial support from the AI-TRANSPWOOD project, funded under the European Union Horizon Europe programme (HORIZON-CL4-2023-RESILIENCE-01-23, Grant Agreement No. 101138191). This project is co-funded by the European Union. Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HaDEA). Neither the European Union nor the granting authority can be held responsible for them.