

Abstract

A Sustainable Path for Composite Tooling: Novel Materials, Design, and Technologies Through FEM and LCA [†]

Gloria Anna Carallo ^{1,*}, Laura Magnasco ¹, Stefano Chiocca ², Andrea Lessio ³, Michela Mattia ⁴, Michele Morbarigazzi ⁵ and Alessio Verdulli ⁶

¹ ESG, Sustainability, and Climate Risk, RINA Consulting S.p.A., 16129 Genoa, Italy; laura.magnasco@rina.org

² Aerospace & Defense R&D, RINA Consulting S.p.A., 16129 Genoa, Italy; stefano.chiocca@rina.org

³ Mechanical Design and Simulation, RINA Consulting S.p.A., 16129 Genoa, Italy; andrea.lessio@rina.org

⁴ Sustainability, Decarb and Materials R&D, RINA Consulting S.p.A., 16129 Genoa, Italy; michela.mattia@rina.org

⁵ R&D Management, Bercella S.p.A., 43040 Varano de' Melegari, Italy; m.morbarigazzi@bercella.it

⁶ Automotive & Motorsport, Bercella S.p.A., 43040 Varano de' Melegari, Italy; a.verdulli@bercella.it

* Correspondence: gloria.carallo@rina.org

[†] Presented at the 3rd International Online Conference on Polymer Science, 19–21 November 2025; Available online: <https://sciforum.net/event/IOCPS2025>.

Keywords: carbon-fiber composites; sustainable materials; additive manufacturing; life cycle assessment; finite element analysis; polymer recycling; automotive

Intro: Production of composite parts requires proper tools, often made of polyurethane boards, implying the use of harmful substances, such as isocyanates. Moreover, the standard approach for tooling manufacturing is subtractive, generating a massive amount of waste: as a thermosetting material, PU boards are not easily recycled nor re-used; hence, they are often landfilled, increasing the burdens associated with composite manufacturing.

Methods: TOOL4LIFE, an EU-Life project, aims to introduce additive manufacturing and design optimization in composite tooling for the automotive industry, along with the use of thermoplastic materials. The innovations simplify tooling (i.e., there is no need for master models), reduce waste scrap (i.e., direct 3-D printing), and allow for tool recycling at the EoL stage in a sustainable manner.

Results: Finite Element (FE) topology optimization analyses supported the definition of a proper design shape for specific tool application, reducing the amount of material mass required and optimizing the 3D-printing process. Life Cycle Assessment (LCA) applied to the selected shape confirmed the reduction in associated environmental impacts with respect to the baseline PU tool.

Conclusions: The combination of FE analysis and LCA, along with the selection of thermoplastic polymers (i.e., PC and ABS), supports a transition towards sustainable materials and processing in composite tooling. It is feasible for application in the automobile sector, whose design and requirements are challenging, indicating potential wider application in other hi-tech industries. This approach proves that sustainability of composites can be achieved without sacrificing technological performance and feasibility.



Academic Editor: Alberto Jiménez Suárez

Published: 14 November 2025

Copyright: © 2025 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Author Contributions: Conceptualization, G.A.C., L.M., S.C. and A.L.; Methodology, G.A.C., L.M., S.C. and A.L.; Data curation: M.M. (Michele Morbarigazzi) and A.V.; Software, G.A.C., L.M., S.C. and A.L.; Validation, G.A.C., L.M., S.C. and A.L.; Resources, M.M. (Michele Morbarigazzi) and A.V.; Writing—Original Draft Preparation, G.A.C., L.M., S.C. and A.L.; Writing—Review and Editing, G.A.C. and S.C.; Visualization, G.A.C., L.M., S.C. and A.L.; Supervision, M.M. (Michela Mattia);

Project Administration, M.M. (Michela Mattia) and M.M. (Michele Morbarigazzi); Funding Acquisition, M.M. (Michela Mattia) and M.M. (Michele Morbarigazzi) All authors have read and agreed to the published version of the manuscript.

Funding: The TOOL4LIFE project has received funding from the European Union’s Programme for Environment and Climate Action (LIFE) under grant agreement N° 101074299-TOOL4LIFE-LIFE-2021-SAP-ENV.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets presented in this article are not readily available because of technical limitations due to intellectual property rights (IPR). Requests to access the datasets should be directed to the authors.

Conflicts of Interest: The authors declare no conflict of interest.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.