29 JUNE - 3 JULY
ACEX2026
RHODES · GREECE

19th International Conference on Advanced
Computational Engineering and Experimenting
29 JUNE – 3 JULY 2026 | RHODES, GREECE

ABSTRACT:

Advancing High-Performance Polymer Engineering Through Integrated Print-and-Coat Manufacturing in High Vacuum

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Fused Filament Fabrication (FFF) in high vacuum presents a transformative approach to polymer engineering by fundamentally altering the thermal and environmental boundary conditions governing the process. It not only improves mechanical properties [1], but also enables the seamless integration of vacuum arc deposition techniques directly into the additive manufacturing workflow, allowing simultaneous fabrication and surface functionalization of high-performance polymers [2].

This study investigates an integrated print-and-coat manufacturing strategy for polyether ether ketone (PEEK), focusing on porous spinal cage structures with tailored mechanical and biological functionality. The application requires a controlled porous architecture to ensure load-bearing performance and promote osteointegration, combined with antibacterial surface properties achieved via in situ coating. The study examines the complex constraints associated with achieving this multifunctionality. In particular, the effects of thermal history along the build direction (z-axis), governed by dynamic heat conduction, as well as extrusion process interruptions due to the coating procedure, are analyzed with respect to interlayer adhesion, residual stresses, and the resulting mechanical properties of the specimens.

To address these effects and enable prediction of future printed parts, a combined thermal–mechanical simulation framework is proposed, together with real-time process control using integrated infrared (IR) monitoring. This approach aims to predict and control process–structure–property relationships under vacuum conditions.

[1] Kühn-Kauffeldt, M., Kühn, M., Mittermeier, C. et al., Prog Addit Manuf 10, 5205–5215 (2025). https://doi.org/10.1007/s40964-024-00897-2

[2] Phruekthayanon, J., Kühn-Kauffeldt, M., Kühn, M. et al., J Mater Sci: Mater Med 36, 109 (2025). https://doi.org/10.1007/s10856-025-06971-7