The Influence of 3D Printing Type and Structure on the Diffusion and Permeability Properties of Polymeric Materials

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Abstract

3D-printed materials, particularly polymeric structures fabricated using Fused Deposition Modelling (FDM), are increasingly used in diverse sectors such as technology, medicine, aerospace, and scientific research. Given this widespread adoption, understanding the environmental behaviour of these materials—especially under vacuum conditions—is essential. In ultra-clean or vacuum-sensitive systems, the phenomenon of outgassing can be particularly problematic, as the emission of volatile organic compounds (VOCs) may degrade the performance of sensitive components, including microcontrollers and nanoscale devices.

This study focuses on how the layer-by-layer deposition inherent to the FDM process affects the outgassing behaviour of polymeric materials. While bulk polymers have been evaluated by institutions like NASA, the nanoscale microstructure formed during 3D printing—determined by the orientation and density of the printed layers—introduces anisotropic diffusion pathways and interfacial voids that can significantly influence gas release. These features fall within the domain of nanoscience, where the control and characterization of matter at the nanometer scale provide new insights into material performance.

We propose that the nanoscale interfacial morphology and void distribution between layers play a critical role in the diffusion and permeation of gas molecules. To test this hypothesis, a wide selection of polymeric filaments will be studied, including common 3D printing materials like PLA, ABS, PETG, PC, and Nylon, as well as advanced composites such as graphene-reinforced filaments, flexible TPU, and blends based on recycled polymers. These materials represent applications ranging from aerospace and electronics to biomedicine and sustainable technologies.

By integrating concepts and methodologies from nanoscience—such as molecular diffusion modelling, interfacial analysis, and nanoscale porosity characterization—this research aims to deepen our understanding of the fundamental mechanisms governing outgassing in 3D-printed polymers and to improve their suitability for vacuum and space-related applications.

References

[1] A.Kurtishaj, I.Hameli, A.Zeqitaj, S.Avdiaj: Measurements of helium permeation in Zerodur glass used for the realisation of quantum pascal, ACTA IMEKO, June 2022 | Volume 11 | Measurements of helium permeation in Zerodur glass used for the realisation of quantum pascal | Acta IMEKO
[2] NASA/TM-20210015404, "Outgassing Data for Selecting Spacecraft Materials" (2021).
[3] Duty, C.E., et al., *"Structure-Property Relationships of 3D-Printed Polymers: Impact of Build Orientation"*, Additive Manufacturing (2017).
[4] ISO/TS 20177, "Additive Manufacturing — Standard test methods for polymer materials — Determination of outgassing properties".
[5] Kim, S., et al., "Correlation Between Microstructural Defects and Outgassing in FDM-Printed Polymers", Polymer Testing (2023).