Microwave-Assisted Ceramic Processing: Raytheon and ORNL Harness Microwave Power for Inside-Out Deposition

Chemical vapor infiltration (CVI) stands as a critical process in manufacturing ceramic matrix composites (CMCs), known for their outstanding mechanical properties in high-temperature applications. However, controlling residual porosity, a key factor affecting CMC quality, remains challenging.

Traditionally, CVI involves infiltrating porous preforms with reactive gases to densify them through chemical reactions. Yet, maintaining isothermal conditions, vital to prevent premature pore closure—a phenomenon where rapid surface deposition hinders reactant diffusion—greatly lengthens processing times.

In response, researchers at Raytheon and Oak Ridge National Laboratory (ORNL) are exploring innovative approaches, notably microwave heating, to improve CVI. Microwaves offer a promising solution by heating materials throughout, potentially enabling inside-out densification. However, understanding microwave heating's mechanisms and its impact on CVI remains challenging due to the complex interplay between microwave frequency, preform size, and resonant wave generation. In this pursuit, Raytheon and ORNL have initiated a pioneering study into microwave-assisted CVI. Utilizing a direct numerical solution (DNS) reacting flow solver, Quilt, and a frequency-domain microwave solver in OpenFOAM, both developed in ORNL, researchers explore temperature inversions through standing waves in porous SiC preforms. Numerical simulations identify critical parameters for resonant wave generation and characterize resulting temperature inversions.

The study integrates high-fidelity direct numerical simulations to model infiltration and deposition within microwave-heated preforms. By combining theoretical insights with computational models, the research illuminates fundamental mechanisms driving microwave-assisted CVI, paving the way for optimized process design and wider industrial adoption. The high-fidelity simulation requires large amounts of computational power to resolve the pore scales, which the industry usually doesn't have.

In essence, this research represents a significant advancement forward in ceramic manufacturing, offering valuable insights into the intricate mechanisms of densification processes. While challenges remain, the exploration of microwave-assisted CVI presents a promising avenue for enhanced control and efficiency in CMC production. Leveraging the findings from this study, the industry can fine-tune process parameters and optimize manufacturing practices, potentially leading to tangible improvements in processing times and material properties. Although full-scale industrial implementation may require further refinement and validation, the potential benefits of microwave-assisted CVI signal a transformative shift in composite manufacturing practices.

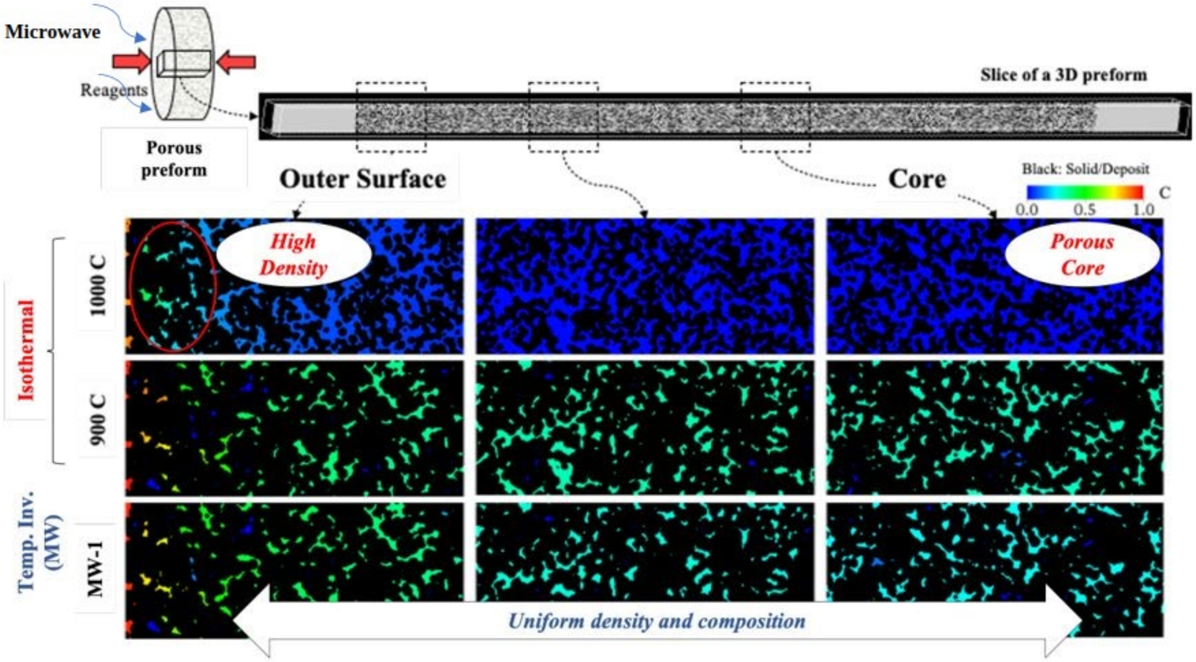

Fig. 1 Visualization of densification from iso-thermal CVI and Microwave-assisted CVI

References

V. Ramanuj, W. Ge, M. Li, R. Sankaran, and Y. She, “Modeling the Effects of Microwave Heating on Densification in Chemical Vapor Infiltration,” ORNL/TM-2023/2855, 1971031, CRADA/NFE2108602, Apr. 2023. doi: 10.2172/1971031.