# Simulation of Manufacturing Process of Ceramic Matrix Composites

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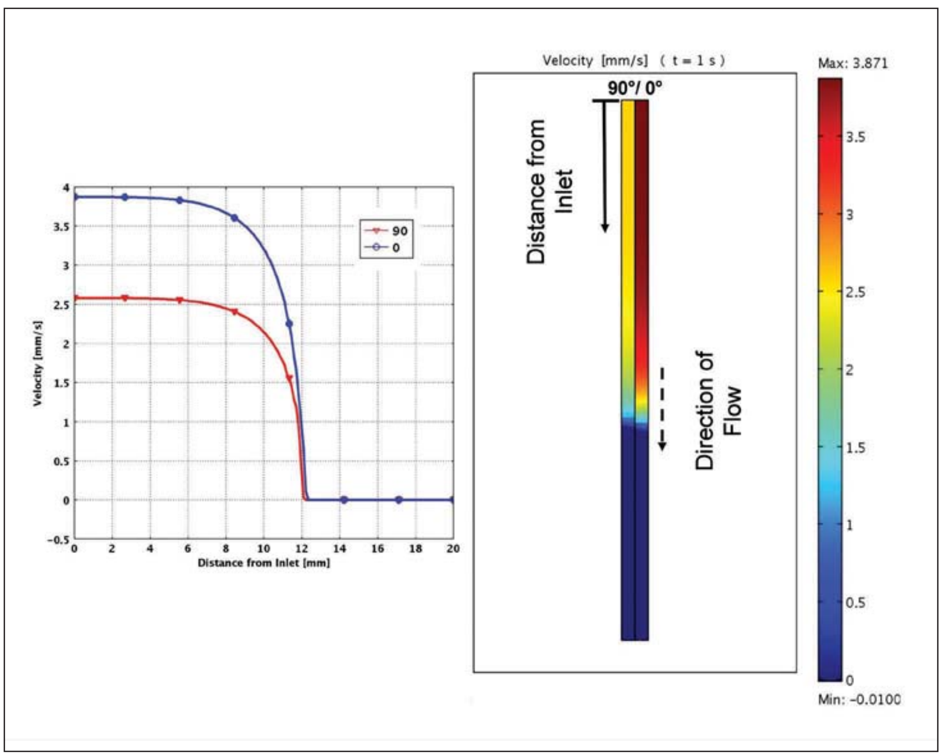
Increasing the temperature at which jet aircraft engines operate would significantly improve thrust and fuel efficiency with reduced emissions. However, current engines operate within 50 degrees of the inherent melting point of the conventional materials used in engine construction, thus new materials capable of operating at higher temperatures for prolonged times must be developed and manufactured. Ceramics and ceramic matrix composites (CMCs) can operate at temperatures in excess of 2000°F but are difficult to fabricate into the complex shapes required for jet engine use and consequently novel manufacturing processes must be developed and processing conditions optimized for routine production of complex components.

To support the development of these innovative manufacturing processes AltaSim Technologies has applied COMSOL Multiphysics® to simulate the manufacturing process of CMCs. Specialized multiphysics simulation tools have been developed to simulate the infiltration of molten material into a ceramic perform. In addition to fluid flow the following physical phenomena must be included to provide a realistic simulation of the CMC production process:

- Unsaturated flow of fluid into a ceramic matrix
- Capillary fluid flow
- Chemical reaction between the fluid and the ceramic matrix
- Volumetric changes associated with the fluid-solid reaction
- Temperature changes associated with the fluid-solid reaction
- Residual stress development and its effect on component shape

Fluid flow described using Richard's and Darcy's equations have been coupled with partial differential equations describing the chemical reaction between the fluid and the ceramic matrix. Simultaneously, heat transfer in a porous medium associated with both the liquid and solid phase, and thermal and dilatational strains associated with the anisotropy of the mechanical properties of the composite material are solved. The resulting simulation is a simultaneous solution that incorporates the relevant, multiple physical phenomena that describe the manufacturing of CMCs. The analysis tool provides a more accurate analysis of the process and has allowed a more rigorous simulation of the interdependent physical phenomena encountered in the manufacturing process. An example of the velocity distributions from a simulation is shown in Figure 1.




**Distribution of the velocity in the fill direction 1s after start of infiltration for a 2 layered CMC, simulation performed by AltaSim Technologies using COMSOL Multiphysics.**

The use of these simulation tools to the analysis of CMC manufacture has allowed designers to analyze the CMC production process and identify the relative significance of the multiple interdependent parameters associated with CMC manufacture. As a result, optimization of critical components of the CMC manufacturing process has been possible thus allowing engineers to reduce cycle time, increase part yield, and optimize the process window for CMC manufacture. The results of analyses using COMSOL Multiphysics have allowed AltaSim Technologies to resolve production issues with new designs prior to mass production and significantly reduce the time and cost of new product development and manufacture.

*This work was performed by Dr. S.P. Yushanov, Dr. J.S. Crompton and Dr. K.C. Koppenhoefer using COMSOL Multiphysics. For more information please contact: K. Koppenhoefer, AltaSim Technologies (www.altasimtechnologies.com), 130 East Wilson Bridge Rd, Suite 140, Columbus, OH 43085.*