Modeling the Relationship Between Porosity and Permeability During Oxidation of Ablative Materials

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Overview

The ablative materials used in thermal protection systems (TPS) undergo oxidation during atmospheric entry which leads to an in-depth change in both permeability and porosity. These properties have a significant affect on heat transfer in a TPS during entry. X-ray microtomography has provided 3D images capturing the micro-structure of TPS materials. In this study, we use micro-tomography based simulations to create high-fidelity models relating permeability to porosity during oxidation of FiberForm, the carbon fiber preform of the Phenolic Impregnated Carbon Ablator (PICA) often used as a TPS material. The goal of this study is to inform full-scale models and reduce uncertainty in TPS modeling.

Micro-Structure of FiberForm

FiberForm is a transverse isotropic material composed of randomly oriented fibers with an average diameter of 11µm. It is strongly inhomogeneous with large variations in material properties at the microscale; its porosity generally ranges from 85% to 91% [1].

Porous Materials Analysis (PuMA)

PuMA [2], a NASA software for microtomography analysis, was used to calculate porosity and simulate uniform oxidation using micro-tomography images of FiberForm. A gray-scale threshold value was specified to distinguish between the solid and void space.

Oxidation Simulation

The oxidation model in PuMA simulates diffusion through porous media as a random walk of oxygen particles with a sticking probability law for surface reactions [2,3].

Permeability Calculations

Permeability was calculated by simulating creeping flow using an explicit jump method in GeoDict [4], a commercial software for micro-structure analysis. The micro-structure was determined using a similar thresholding method to that in PuMA.

Verification using Array of Cylinders

Permeability calculations were first done on a square array of cylinders for verification. The porosity was varied by changing the radius of the cylinders and keeping the domain size constant. The results were compared to a deterministic model from Shou et al. [5].

References


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