Sandia National Laboratories

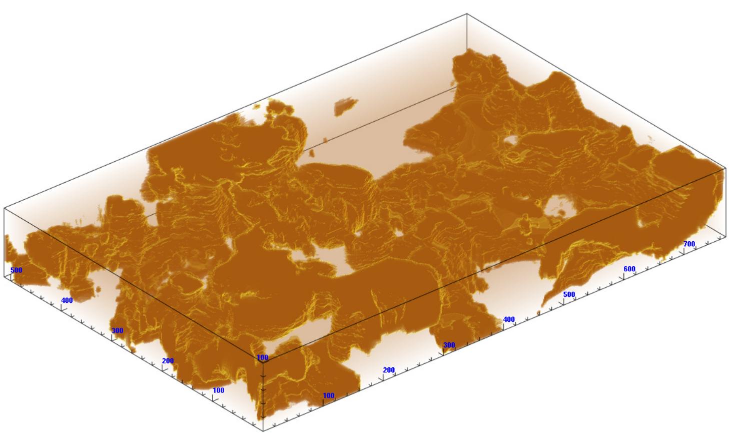
Microscale Characterization and Modeling of Porous Media

Need

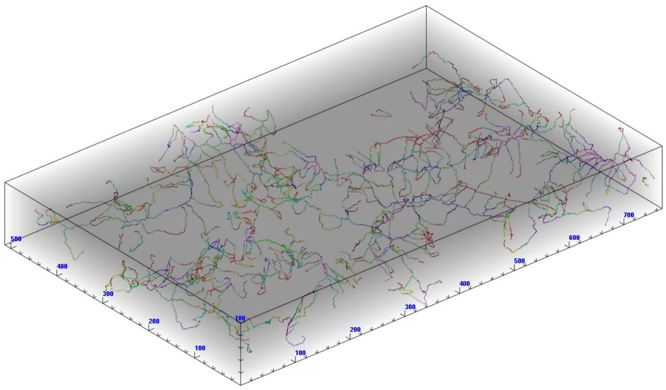
Natural as well as many engineering materials exhibit complex pore structures which greatly influence their mechanical and physical properties, including elastic moduli, strength, failure behavior, poroelastic parameters, seismic velocity, electrical conductivity, and permeability. The extent to which the macroscopic properties of an arbitrarily complex porous medium can be accurately predicted using microscale modeling follows directly from the sophistication of the model, which in turn depends upon the completeness of the microgeometric description used as input. Conventional approaches have relied on 2D imaging techniques from which first-order geometric parameters such as volume fraction and specific surface area can be derived using well-known geometric probability theory. However, 2D techniques cannot constrain higher-order geometrical attributes, such as the topology, coordination, or connectivity of the two-phase network.

Description

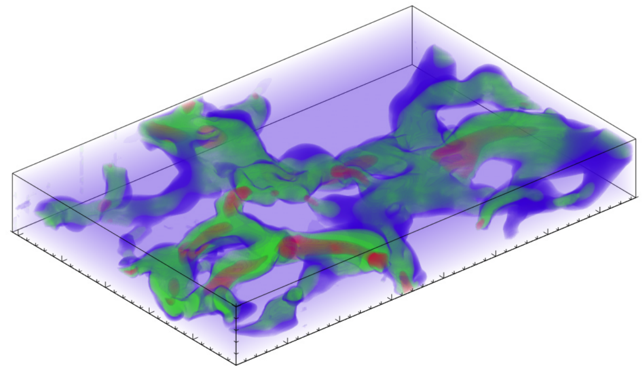
Researchers at Sandia National Laboratories have developed techniques to apply laser scanning confocal microscopy to non-biologic (solid) porous media for 3D imaging. High-resolution (to 0.1 micron) volumetric image data are obtained by impregnating the void space of a porous sample with an ultra-low viscosity epoxy doped with a fluorochrome that is excited under laser illumination during “optical” sectioning. Volumetric image data, consisting of fluorescence intensity for ~50-100 million voxels in **XYZ** space, are segmented into void and solid phases from which the 3D structure of the two-phase medium can be reconstructed. Several different approaches for segmenting the data have been implemented in computational algorithms. The *n*-point correlation functions are used to quantify first-order geometric parameters, and algorithms based on a medial axis analysis are used to quantify spatially distributed geometric attributes of the two-phase medium. The binarized volumetric data are used to automatically generate a 3D mesh for numerical flow simulations based on the Lattice Boltzmann Method.



3D reconstruction of the pore space in sandstone (768 × 512 × 101 voxels at 1 micron resolution)



3D visualization of the medial axis (akin to the "skeleton" of the pore space) for the reconstructed volume



Isosurfaces of steady state flow velocity from 3D LBM simulation

Geoscience and Materials Science Examples

The 3D confocal imaging technique has been applied to a variety of porous engineering and natural materials. *Fredrich et al.* (1995) described application to various geomaterials, including sandstone, limestone, granite, marble, and dunite, and showed how the 3D information can be used to derive new insight into fluid transport behavior and the micromechanics of brittle fracture. *Fredrich and Lindquist* (1997) described the derivation of first-order and higher-order geometric parameters from the volumetric confocal image data using medial axis analysis, and showed how such analyses can be used to quantify the loss of connectivity in a pore network as the percolation threshold is approached. *Vetter et al.* (1996) described application of the 3D imaging technique to super-screw dislocations in silicon carbide single crystals, and *Marschall et al.* (1997) described application to microstructural characterization and transport modeling of porous ceramic insulations used in the US Space Program. *Fredrich and O'Connor* (1998) described how the 3D image data are used in numerical simulations of fluid flow at the pore-scale using parallel and distributed computing methods.

References

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