The Porous Microstructure Analysis (PuMA) software

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Abstract

The open-source Porous Microstructure Analysis (PuMA) software [1,2] was implemented to offer an efficient framework for determining material characteristics from 3D microstructures. Its development was inspired by progress in X-ray microtomography, an imaging technology that captures the internal structure of materials in 3D, and even in a 4D temporal context. Over recent years, this method has transformed the domain of materials science due to its capability to non-destructively examine material microstructures while presenting digital data about their geometrical details. It has provided insights into materials relevant to several NASA missions, including heatshields, parachute fabrics, meteorites, and other advanced composites.

PuMA, in its current version 3, delivers an array of features, spanning from basic geometric insights of a microstructure to intricate anisotropic thermo-elastic and chemical behavior. Specifically, the software evaluates morphological attributes (specific surface area, volume fractions, mean intercept lengths, orientation [3]) and physical characteristics (conductivity [4], elasticity [5], permeability [6], and tortuosity [7]). Additionally, it can model material degradation processes, such as oxidation [8] and surface chemistry interactions. The software can generate synthetic microstructures, from straightforward geometrical designs to intricate woven and non-woven geometries. Coupling material generation and characterization enable parametric studies and sensitivity analysis to optimize the microstructural performance and inform design decisions and reliability assessment based on uncertainty quantification.

A recent addition to PuMA includes the TomoSAM plugin [9], devised to incorporate the cutting-edge Segment Anything Model (SAM). SAM is a promptable deep learning model that can identify objects and create image masks in a zero-shot manner, based only on a few user clicks. The synergy between these tools aids in the segmentation of complex 3D datasets from tomography or other imaging techniques, which would otherwise require a laborious manual segmentation process.

Keywords: Tomography, Microscale modeling, 3D Segmentation, Conductivity, Orientation, Elasticity, Permeability

References

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