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Multi-scale flow, permeability, and heat transport in building materials

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Permeability and heat transport through building materials ultimately dictates their insulatory performance over a buildings service lifetime. However, characterisation of building materials is challenging because porous building materials are heterogeneous and their macroscopic physical properties (e.g. permeability, thermal, and mechanical) depend on their micro scale characteristics, i.e. the local distribution and features of the solid components and the connectivity of the spaces between them. Large-scale testing can measure these macro-scale properties, but often does not give insight into the underlying micro structural properties that ultimately leads to optimisation. Thus, a knowledge of the 3D structure is therefore required to assist in the development and implementation process for new materials. Experiments combining X-ray microtomography with numerical modelling are an accepted method of studying pore scale processes and have been used extensively in the oil and gas industry to study highly complex reservoir rocks. However, despite the obvious similarities in structure and application, these techniques have not yet been widely adopted by the building and construction industry.

We have investigated the pore structure of several building materials, both conventional and historic using X-ray tomography and direct numerical simulation. Five samples were imaged at between a 4- and 15-micron resolution inside a micro-CT scanner. The porosity and connectivity were extracted with the grain, throat, and pore size distributions using image analysis. The permeability, velocity, and thermal conductivity were then investigated using GeoChemFoam, our highly versatile and open- source numerical solver. We found that each material had a unique, heterogeneous, and sometimes multi-scale structure that had a large impact on the permeability and thermal conductivity [Figure 1]. Furthermore, we found that the method of including sub resolution porosity directly affected these bulk property calculations for both parameters, especially in the materials with high structural heterogeneity. This is the first multi-scale study of structure, flow and heat transport on building materials and this workflow could easily be adapted to understand and improve designs in other industries that use porous materials such as fuel cells and batteries technology, lightweight materials and insulation, and semiconductors.

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Figure 1: The local heat flux (J) through Bentheimer building stone (left) and a historic brick (right).

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