Diverse Models for Graphite Brick Deformation and Stress State in UK AGR Nuclear Reactors

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Introduction: The UK Advanced Gas-cooled Reactor fleet, operated by EDF Energy, utilise a graphite core consisting of a lattice of around 3000 annular bricks (Figure 1). Due to irradiation, oxidation and thermal effects, the bricks deform and loose mass as they age. Of key concern is the late-life behaviour of the bricks, in particular the predicted time at which brick shrinkage reverses into expansion, generating large stresses and potentially giving rise to cracking at the keyways. The objective of this work was to create a diverse model of the evolution of a graphite brick and explore the sensitivity of brick deformation and stresses to variability in different properties and different modelling assumptions.

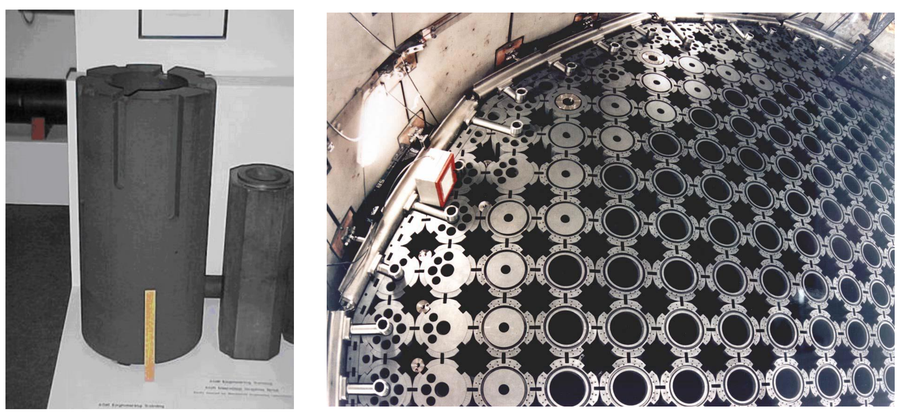

Figure 1. An individual graphite brick and the core lattice

Computational Methods: A calibrated 3D non-linear model has been built using the COMSOL Multiphysics® Geomechanics and Structural Mechanics modules. Irradiation induced dimensional change ("creep") is implemented using an ODE interface. The thermomechanical properties are coupled to field variables (neutron dose and temperature) using physically-inspired statistical models fitted to measurements from reactors. Sensitivity studies were carried out using the batch sweep option.

Two half-height 90° brick geometries are used as shown in Figure 2. The second geometry explicitly represents the coolant gas holes in the brick.

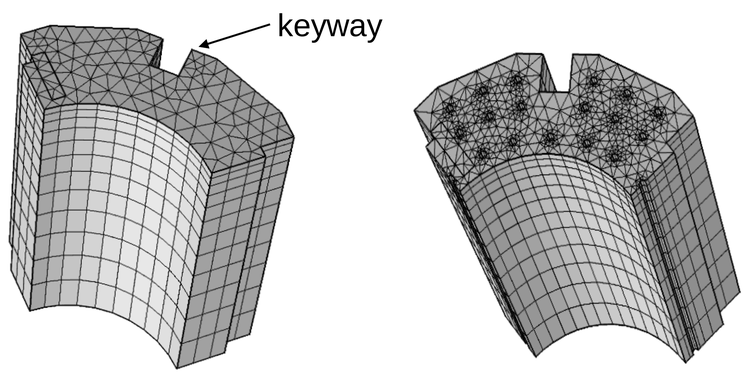

Figure 2. Different COMSOL geometries used

Results: 162 sensitivity calculations were run, varying five different properties: dose gradient, weight loss rate, dimensional change rate, secondary creep rate and the presence of a fuel end dose depression.
An example of the brick deformation and stress evolution is shown in Figure 3.

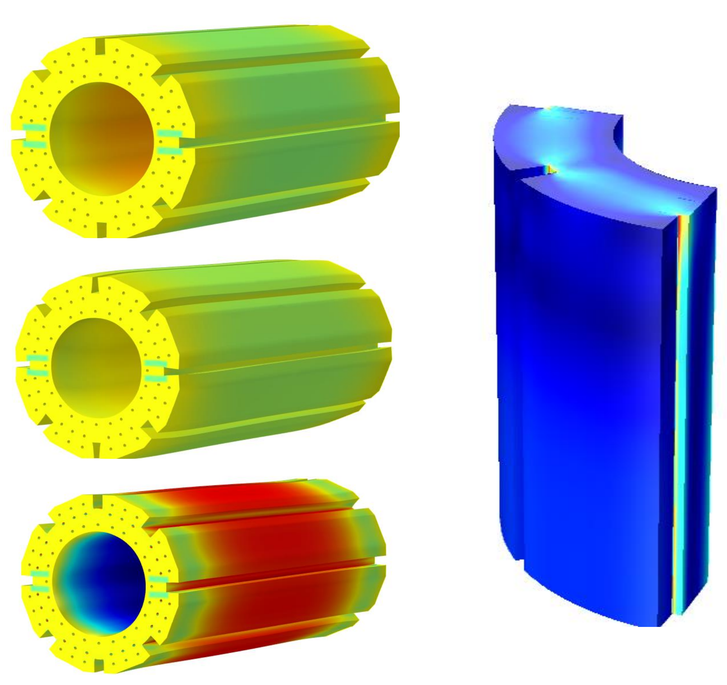

Figure 3. Whole brick deformation and axial (left) and von Mises (right) stress

Dimensional change was shown to be the most important factor for the evolution of brick shape and is also important for stresses (Figure 4). Measurements from reactors compared well with model results.

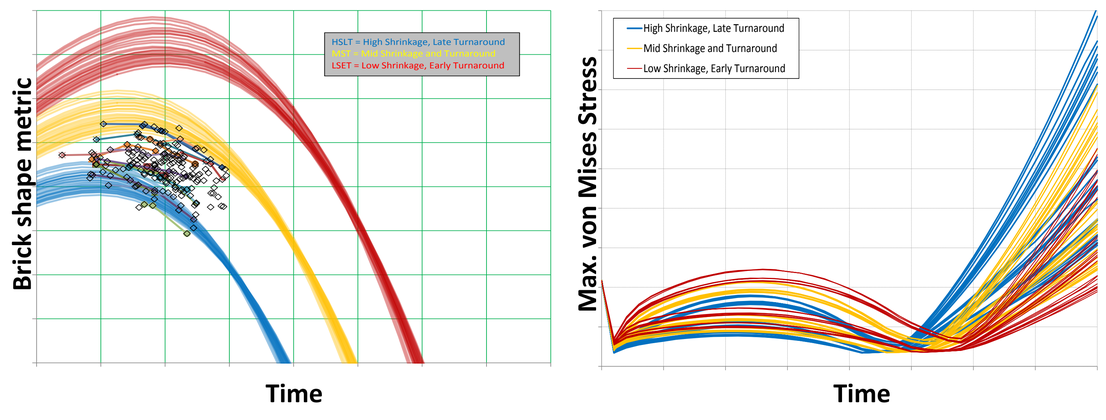

Figure 4. Evolution of brick shape metric and stress for the different values of dimensional change rate.

Conclusions: The development of a diverse COMSOL Multiphysics® model has enabled exploration of the inherent variability in reactor graphite cores, and has revealed which processes and properties have the largest impacts on bore deformation. A further series of sensitivities studies is being undertaken with the aim of developing the capability to calculate likelihoods of keyway root cracking.

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