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

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Abstract

The UK Advanced Gas-cooled Reactor fleet, operated by EDF Energy, utilize a graphite core to act as a neutron moderator and provide the structure into which fuel and control rods are inserted. This core consists of a lattice of around 3000 approximately annular bricks assembled in columns of 12 bricks (each brick is approximately 0.84 m tall and 0.23 m in radius - see Figure 1) arranged in a mutually supportive hexagonal pattern via graphite 'keys' that link into 'keyways' on the outside of the bricks. The bricks are subject to temperatures of approximately 430 °C with the fuel being located down the central annulus of each fuel brick. The combination of radiation dose gradients, temperature differentials, axial loading and oxidizing gases causes the bricks to deform, loose mass and change material properties during their lifetime, as well as building up stresses within the bricks (see Figure 2). The neutron flux also causes the bricks to 'creep', producing strains many factors larger than the elastic strain alone.

Of key concern is the late-life behavior of the bricks, in particular the predicted point at which the brick shrinkage (which causes the main brick deformation) reverses into expansion. This expansion will occur at the brick bore first, reversing the stress state of the brick and generating potentially quite large tensile stresses at the roots of the brick keyways, potentially giving rise to cracking of the bricks at the keyways. Such cracks, in sufficient numbers, may threaten core integrity. Being able to make accurate predictions of the likelihood and timing of keyway root cracking is therefore a key concern in managing the AGR fleet safely and economically to the end of life.

The objective of the work using COMSOL Multiphysics software was to create an alternative ('diverse') representation of the evolution of graphite bricks, using simpler models than the existing models used by EDF Energy, focusing primarily on physically-inspired statistical models using measurements on the reactors. COMSOL was considered ideal for this task as it allows for the rapid and transparent inclusion of custom complex coupled processes, enabling different physical model forms and brick geometries (Figure 3) to be tested against the available data.

A calibrated 3D non-linear mechanical model has been built using the COMSOL Geomechanics and Structural Mechanics modules. This has been extended to examine the consequences of inherent variability in the reactor graphite core and the potential correlations between brick shape and the likelihood of keyway root cracking for that brick. 162 cases were run using COMSOL

batch functionality and the results analyzed.
A series of further studies and analyses are currently being undertaken with the aim of developing the capability to calculate likelihoods for keyway root cracking.

Figures used in the abstract

Figure 1: An individual graphite brick

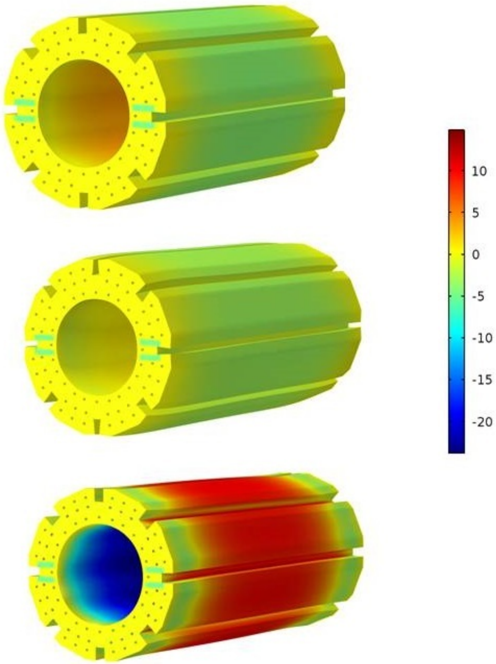

Figure 2: Whole brick deformation (exaggerated 7x out of the axial plane) and axial stress (MPa) for the polygonal model with diffusion holes.

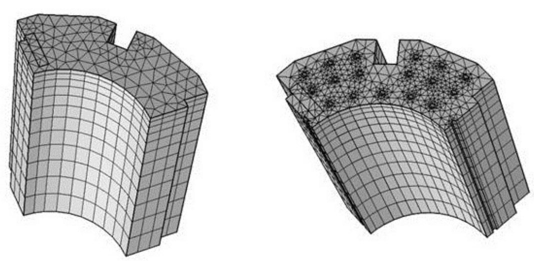

Figure 3: Different COMSOL geometries

Figure 4