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Configurational mechanics for fracture propagation in nuclear graphite

The reactor core of the majority of the UK's fleet of civil nuclear power plants is comprised of thousands of graphite bricks that serves as both a moderator for the nuclear reaction and structurally houses the fuel. Over time, irradiation degrades the graphite, and this has led to cracks in the reactor core that compromises structural integrity and can potentially impair control of the nuclear reaction. The aggressive environment of the reactor core cannot be experimentally replicated. The core cannot be replaced and represents the major life-limiting factor of these power plants. Understanding the behaviour of the graphite core is paramount to the assessment of structural integrity, safe operation and life extension. The latest developments in the finite element modelling and simulation of crack propagation will be presented.

Configurational mechanics (CM) provides the theoretical basis for our work on crack propagation. This approach has a strong physical motivation, exploiting the 1st and 2nd laws of thermodynamics to establish crack front equilibrium and the crack path direction, resulting in an implicit crack propagation formulation. In addition, several numerical techniques to implement this theory within a finite element analysis software framework (MoFEM, http://mofem.eng.gla.ac.uk) have been developed. The result is the ability to simulate propagating cracks in 3D solids that are discretely and continuously resolved by adapting the FE mesh in a smooth manner (exploiting the crack front equilibrium condition), thereby avoiding the need for enrichment.

The main driver for crack propagation in nuclear graphite bricks is the complex internal stress state, rather than externally applied mechanical loads. Therefore, the computational framework has recently been extended to capture the process of unstable crack propagation driven by the internal stresses. Several numerical examples will be presented.