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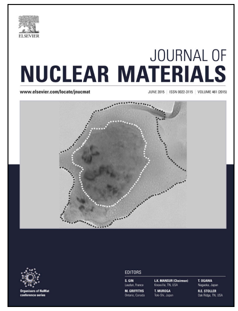

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On the damage and fracture of nuclear graphite at multiple length-scales

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Abstract Gilsocarbon graphite, as a neutron moderator and load-bearing component in the core of the UK fleet of Advanced Gas-Cooled Reactors, possesses complex microstructural features including defects/pores over a range of length-scales from nanometres to millimetres in size. As a consequence, this material exhibits different characteristics when specimens of different length-scale are deformed. In this work, the deformation and fracture of this material have been characterised using *in situ* methods for specimens of micrometre size (meso-scale) and the results are then compared with those measured one length-scale smaller, and those at the macro-scale. At the micro-scale, sampling a volume of material (2x2x10 µm) excludes micro- and macro-size pores, the strength was measured to be as high as 1000 MPa (an elastic modulus of about 67 GPa). When the specimen size is increased by one order of magnitude to the meso-scale, the strength is reduced to about 100 MPa (an elastic modulus of about 20 GPa) due to the inclusion of micro-size pores. For larger engineering-size specimens that include millimetre-size pores the strength of the material averages about 20 MPa (an elastic modulus of about 11 GPa). This trend in the data is discussed and considered in the context of selecting the appropriate data for relevant multi-scale modelling.

Keywords: micro-mechanical testing, multiple length-scale, nano-indentation, elastic modulus, graphite

1. Introduction

Commercial graphites such as those used as moderators in the reactor cores of civil nuclear power plants have quasi-brittle characteristics [1-3]. In general, these materials are multi-phase, aggregated and porous, and the overall microstructures have been considered to cover multiple length-scales [4-6]. In the case of as-manufactured Gilsocarbon graphite used in the UK fleet of Advanced Gas-cooled Reactors (AGRs), there is about 20 vol.% porosity consisting of pores ranging from nanometres to millimetres in diameter [6-7]. This porosity is distributed between the filler particles (Gilsonite coke) and the binder phase which comprises graphitised ground fine filler particles and coal tar pitch. Furthermore, the microstructure of this material is modified by neutron irradiation and radiolytic oxidation in the CO_2 gas environment of the AGRs. This leads to an overall reduction in strength, distortion and potential fracture of the graphite bricks that make up the reactor core [3, 7]. Therefore, it is of paramount importance to understand the deformation and fracture of this material prior to irradiation and after service. To measure the physical and mechanical properties, irradiated graphite samples are removed periodically either from the core bricks using trepanning or as surveillance samples, limiting the sample sizes that are available for laboratory tests. As a consequence, mechanical property measurements obtained from small-scale testing have been recognised as advantageous for the investigation of such radioactive materials [8-10].

There are various experimental configurations available for micro-mechanical testing including nano-indentation, micro-pillar compression and micro-cantilever bending [11-14]. Since nuclear graphites have complex and porous microstructures, *ex situ* testing such as nano-indentation does not provide