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FOCUS ON IMAGING

In Application

Observation and Quantification of Three-dimensional Crack Propagation in Poly-granular Graphite

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Introduction

Graphite is an important component in several current and future design of nuclear fission reactors, and the structural integrity of the graphite moderator is critical to the safe operation of UK's Advanced Gas Reactors (AGRs). Radiolytic oxidation degrades nuclear graphite strength while fast neutron irradiation causes dimensional changes which in combination can cause damage to the reactor core.

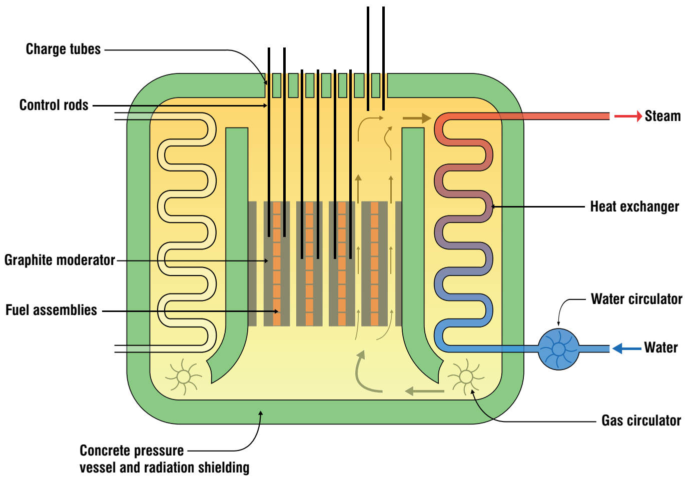

***Figure 1:** Schematic AGR reactor*

Previously only two dimensional Digital Image Correlation (DIC) has been used for quantitative in situ studies of damage nucleation in graphite. DIC is useful in making investigation at the surface of a material but it cannot reveal the sub-surface deformation. Digital Volume Correlation (DVC) makes an analysis of the entire volume image acquired from X-ray CT systems, and this study demonstrated its ability to quantify damage propagatation within the specimen. DVC is able to provide insights and quantitative measurements of the processes of damage development in graphite.

Experimental Setup

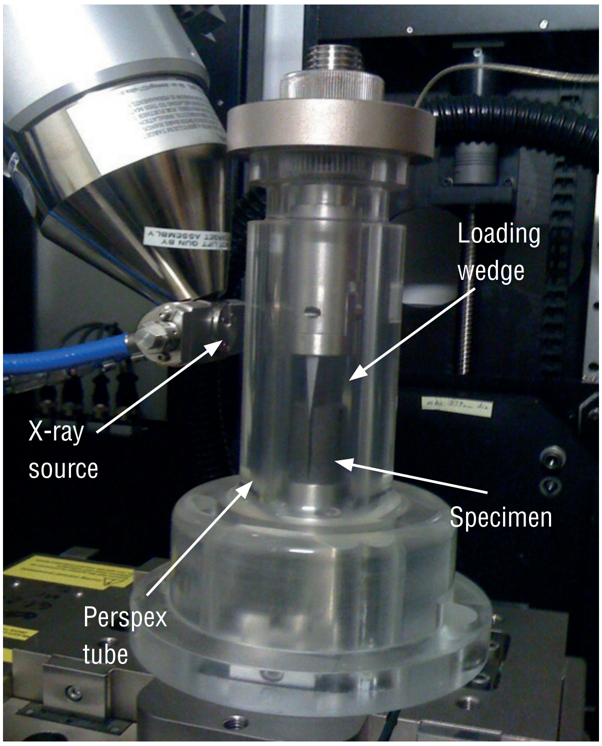

***Figure 2:** Specimen within the loading rig*

A short-bar chevron notched specimen of polygranular-graphite material was the test subject, having a diameter of 25 mm and featuring a notch of angle 54 ° and width 1 mm. Ligament length was 23 mm and the whole length of the specimen was 35 mm. The specimen was mounted in a screw-driven loading rig (DEBEN) which drove a sharp wedge into the notch thus initiating the crack. A 320 kV Nikon Metris custom XCT scanner was used to image the specimen (Manchester X-ray Imaging Facility, University of Manchester) with final image resolution of 8 µm per voxel.

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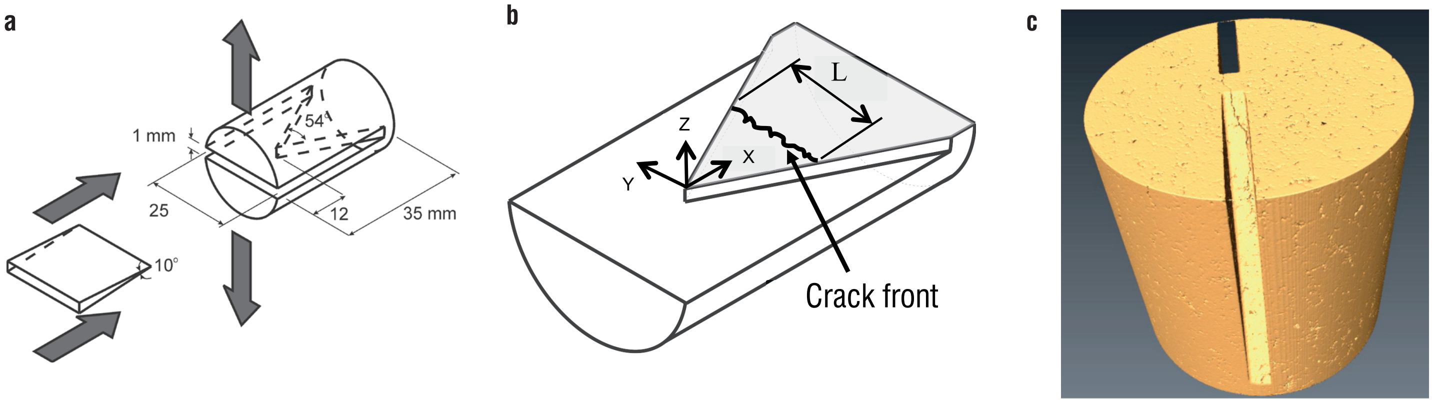

***Figure 3:** Overview of the short-bar chevron notch test (a) dimensions of specimen, (b) half the specimen highlight crack initiation and propagation, (c) reconstructed volume.*

Results

Five scans of the specimen were acquired : no load, wedge driven to 230 N, wedge removed, wedge driven to 266 N, wedge removed. DVC calculation parameters employed a multi-pass starting sub volume size of 256 x 256 x 256 voxels and final size 32 x 32 x3 2 voxels with 75 % overlap. The strain resolution calculated in a region remote from the crack tip where zero strain is expected was between 0.016 % and 0.035 %.

DVC was successfully applied to XCT data of nuclear graphite. It allowed the calculation of full volume displacement and strain results, and enabled the crack opening displacement under load to be measured (see Figure 4). Due to the sub-pixel precision of DVC, cracks can be identified where they are not visible in the raw image. Crack opening was greatest closest to the notch tip, and at the crack tip was uneven in topology. The uneven crack front is attributed to local interactions with the coarse nuclear graphite microstructure which contains Gilsonite coke particles up to 1 mm in size. Strip-yield type opening ahead of the crack tip was observed, providing evidence for quasi-brittle behaviour of graphite due to microcracking initiating the fracture process zone. Work continues with the group in coupling DVC with Finite Element (FE) approaches.

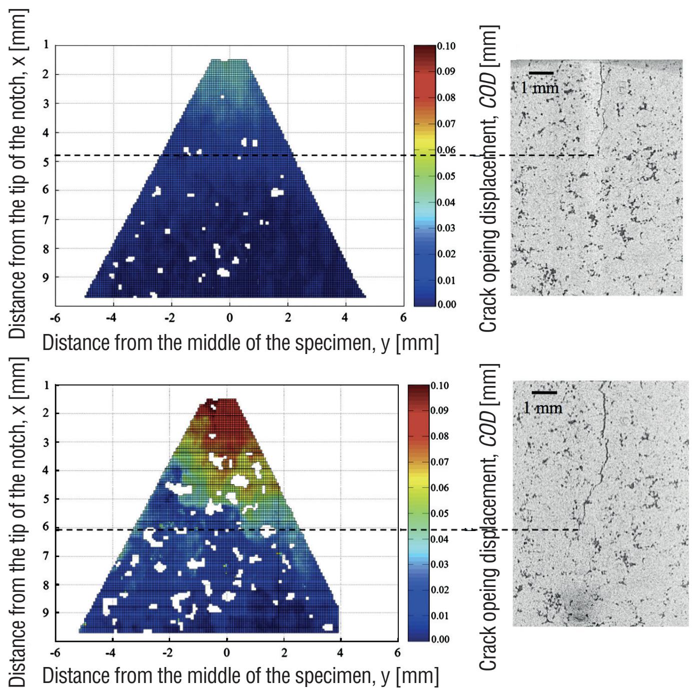

***Figure 4:** Crack opening displacement and crack length measurement.*

Further information can be found in the related paper: Mostafavi et al. (2013) Engineering Fracture Mechanics 110, 410-420.

02/14

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