OXFORD MARTIN SCHOOL

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Oxford Materials

Nuclear Materials

Observation of Crack Propagation in Polygranular Graphite using Tomography and Digital Volume Correlation

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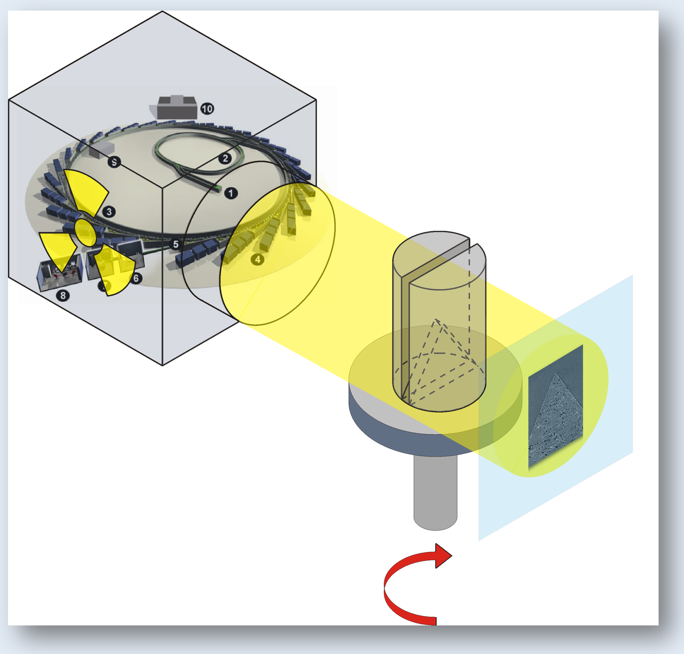
Our work aims to understand the interaction between microstructure and crack propagation in quasi-brittle materials, such as nuclear graphites. The techniques are also applicable to feature-rich, heterogeneous brittle materials such as ceramic-matrix composites, thermal barrier coatings and concretes, which are key structural materials in current and next generation nuclear power.

Engineers assure the safety of structures containing defects by Structural Integrity Assessment (SIA). SIA of nuclear graphite is critical to the continued safe operation of the UK's Advanced Gas Reactors (AGR). Radiolytic oxidation degrades its strength (amongst other properties), while neutron irradiation causes dimensional change, which develops tensile stress at critical locations. Ultimately, this would cause the moderator bricks in the reactor core to fracture; this is a major limit to reactor lifetime as they also act as channels for fuel and control rods. Confidence in graphite integrity is a major challenge to AGR lifetime extension and over-conservative assessments that end the lifetime prematurely will be detrimental to the UK economy.

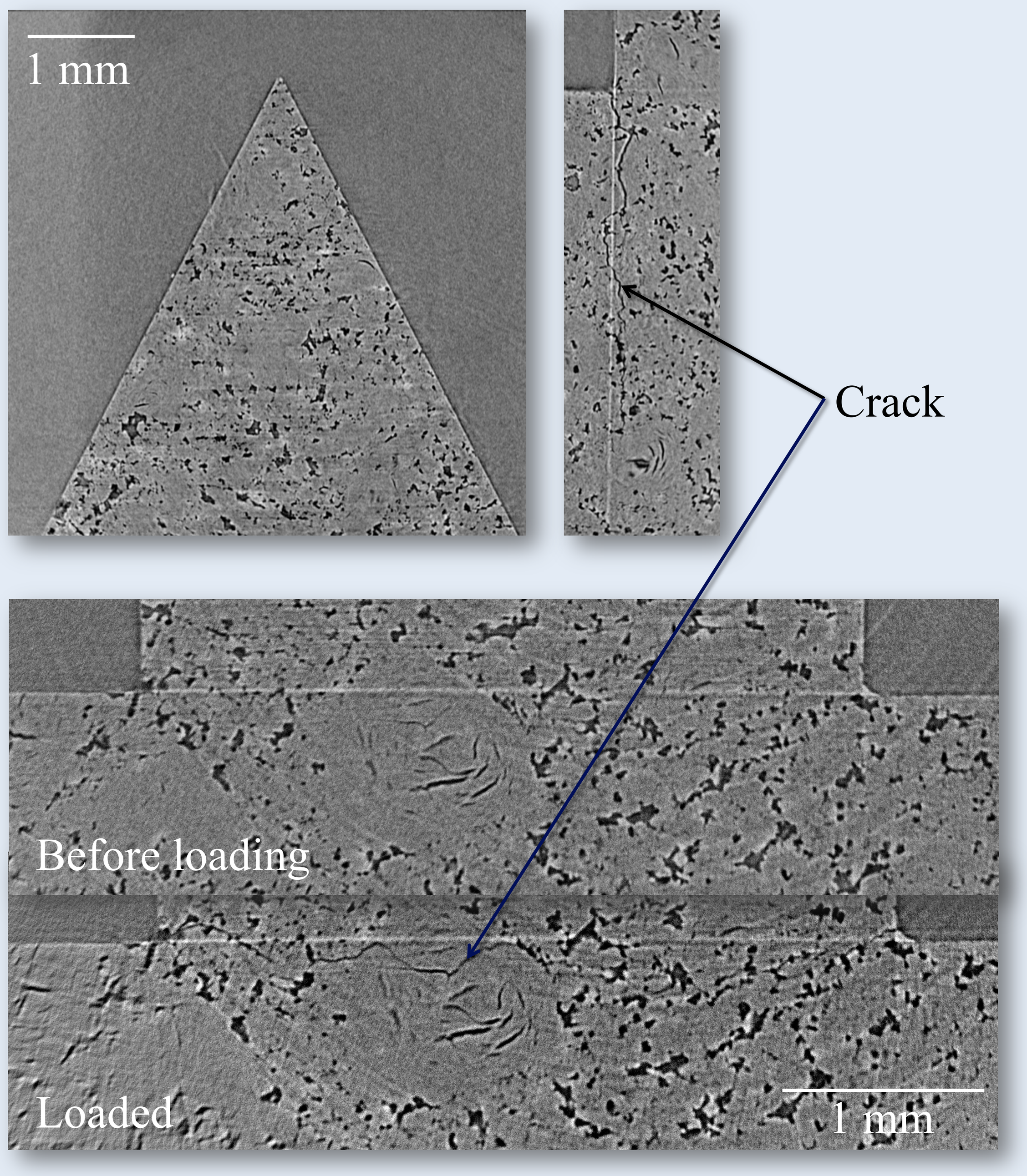
Detailed observations of fracture processes, using three-dimensional characterisation techniques, are being used to validate models for the effects of microstructure degradation on fracture behaviour to support the SIA of nuclear graphite components.

X-ray computed tomography has recently been applied to study crack propagation, in-situ, in nuclear graphite. Thousands of individual radiographs, obtained as the sample is progressively rotated, are processed to obtain high-resolution three-dimensional images of the microstructure.

Stable crack propagation is achieved using a short chevron-notched specimen. Successive images of the propagating crack, and its interaction with the porous microstructure are obtained.

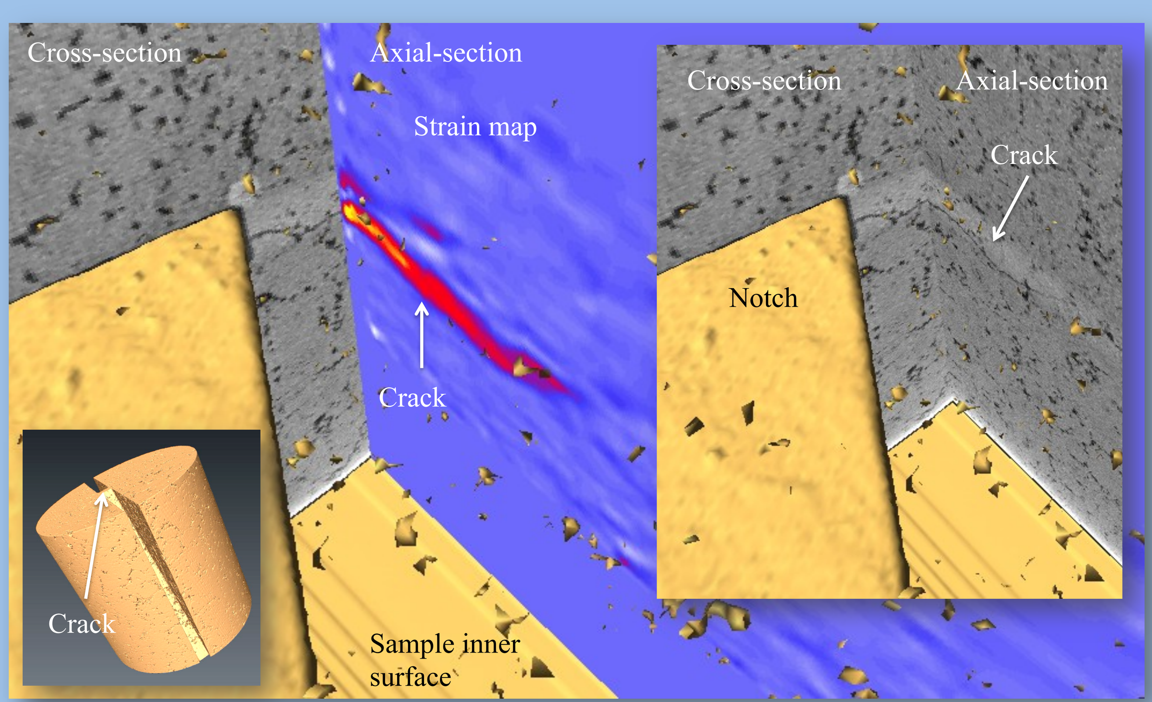


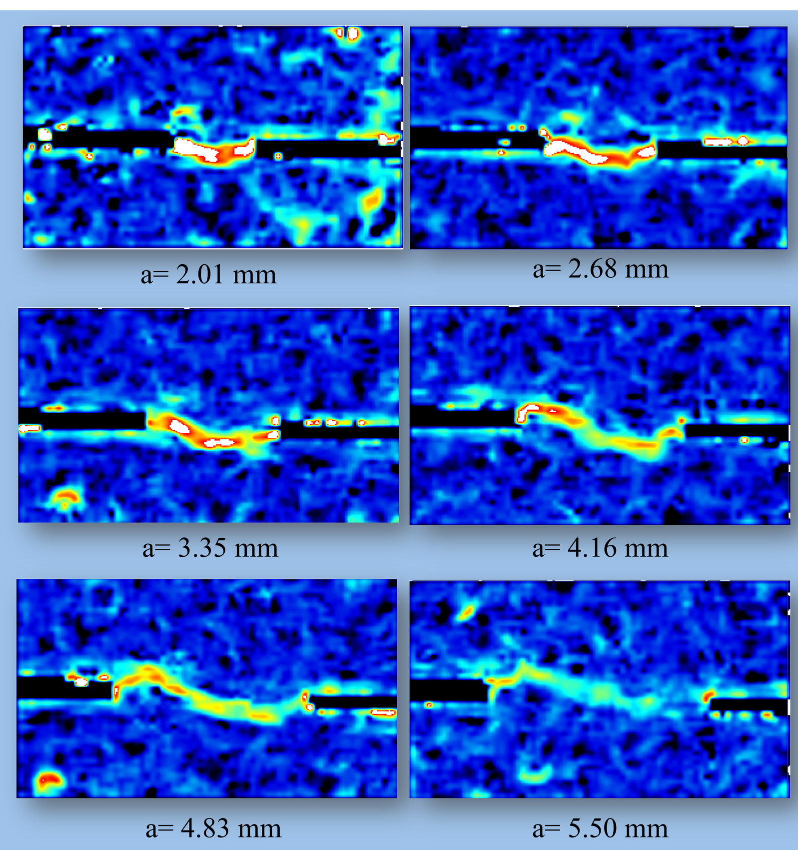
X-ray Computed Tomography (schematic)

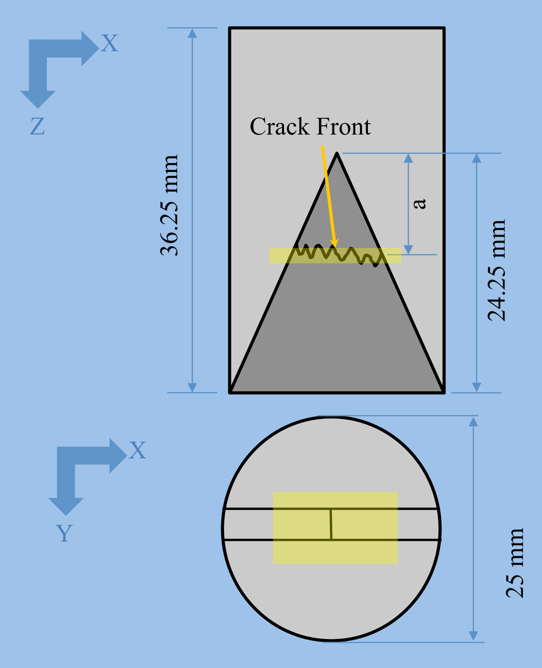


Preliminary Tomographic Reconstructions

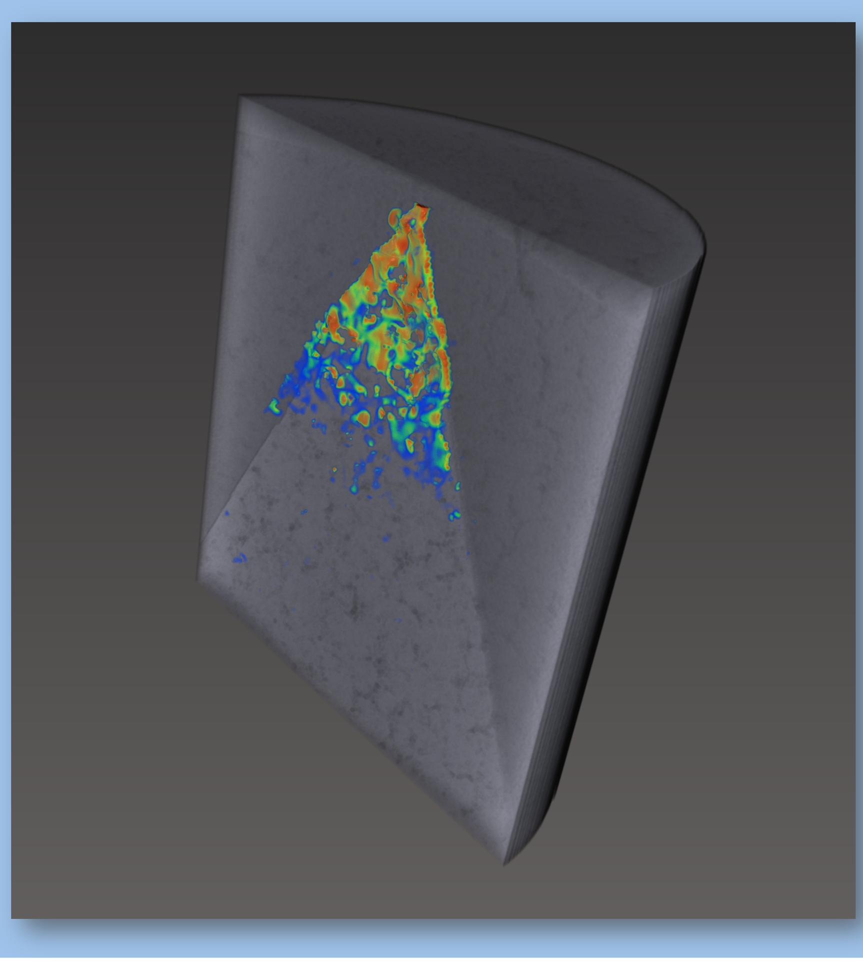
(Image artifact removal to be applied)





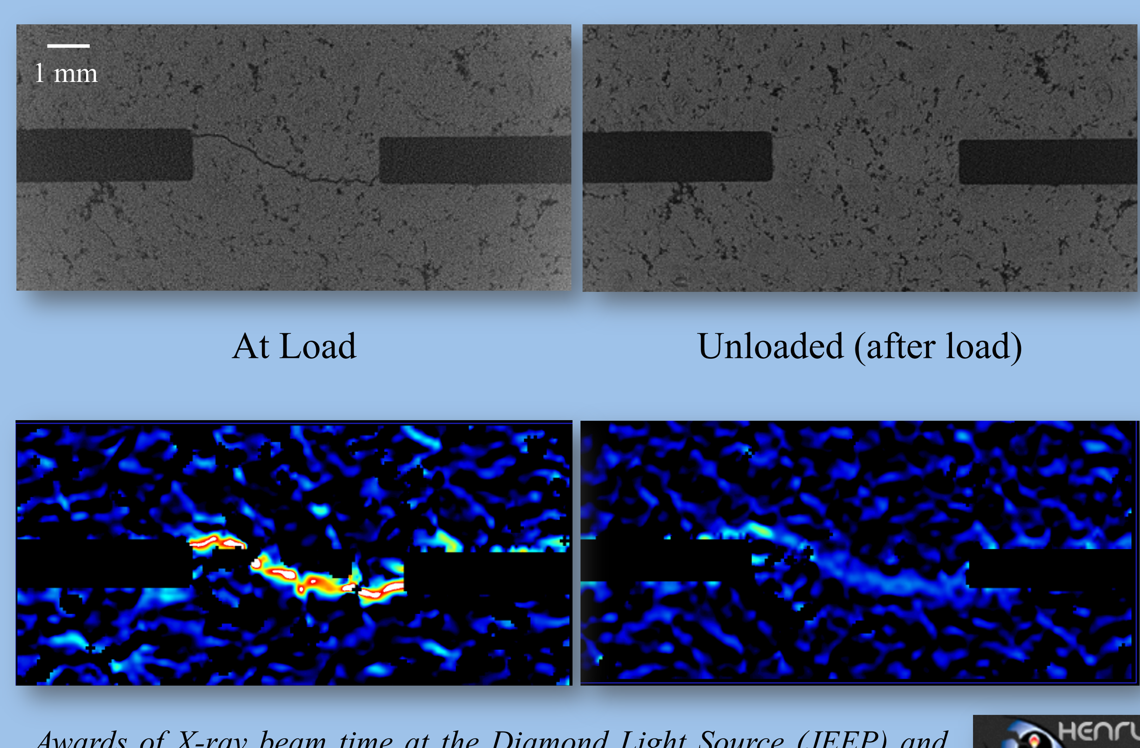


Schematic view of the specimen



The three-dimensional images obtained by tomography are analysed using Digital Volume Correlation. This is a highly sensitive technique to measure displacement vectorsbetween successive images within the material. Differentiation of the displacement field produces an effective strain field, which can be used to visualise and quantify the crack opening behaviour as well as the elastic and inelastic strains around the crack. The mechanical crack driving force (i.e. the J-integral) may also be obtained via analysis of the displacement field.

The images to the left show the strain field due to the crack opening, superposed on tomographic images of the microstructure and sample. The images to the right show virtual cross-sections near the centre of the specimen, which show the heterogeneity of the crack opening, and the residual strains observed when the load is removed. There is evidence of crack face interactions, which contribute to R-curve behaviour (rising toughness with crack propagation). R-curve behaviour is an important element in predicting defect tolerance in the SIA of engineering components.



Awards of X-ray beam time at the Diamond Light Source (JEEP) and the University of Manchester Henry Moseley Imaging Facility are gratefully acknowledged.

Henry Moseley X-ray Imaging Facility

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