Relationships between the Microstructure and Behaviour of Nuclear Graphite

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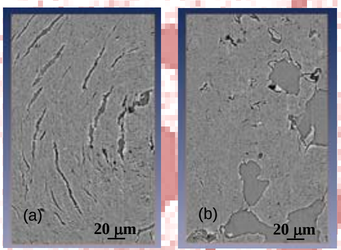
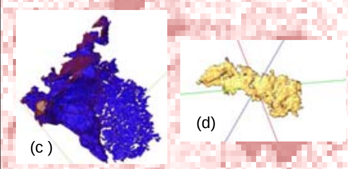
Introduction

Graphite is used for many of the major structural components in gas-cooled reactors. It can be considered a composite material due to its complex, multi-phase microstructure. During operation, the graphite undergoes radiolytic oxidation leading to increased porosity and a degradation of its mechanical and physical properties. Plant lifing and risk assessment is dependent on a good understanding of the relationships between the microstructure, porosity, and these properties. In the present study, X-ray microtomography (XMT) is used to address two issues: the effect of porosity on thermal diffusivity; crack propagation and R-curve behaviour. XMT allows 3-D images of the internal structure of a body or material to be obtained non-destructively at high spatial resolution.

Porosity and Thermal Diffusivity

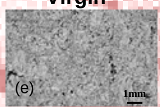


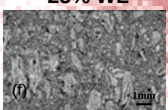
High resolution tomography at the ESRF synchrotron source enables individual pores to be imaged in both inclusion (a) and matrix (b) phases.

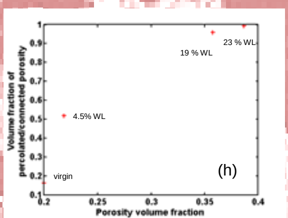


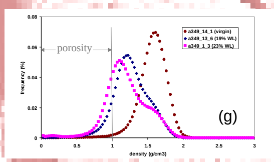
Morphological analysis is performed to categorise the porosity as isolated (d) or continuous (c). The isolated pores are further characterised as either spheres, oblate or prolate ellipsoids of a given aspect ratio.

A series of graphite samples were thermally oxidised to simulate radiolytic processes. They were imaged and characterised using laboratory XMT (e,f) to determine the overall and continuous porosity (g). This shows that the continuous porosity increases with weight loss (h). Thermal diffusivity was determined by laser flash.



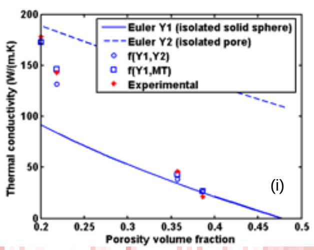






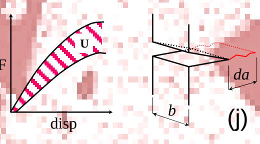
Models (*Meredith-Tobias* and *Euler*) for the effect of porosity on thermal properties were studied. An convolution approach similar to *Cernuschi* was adopted. Here the influence of isolated pores of known geometry is combined with that of continuous porosity.

The pore characterisation by XMT was used directly as input for the models (i). The predictions are in remarkable agreement with the measured values. The approach can be developed to allow predictions of other physical and mechanical (strength, modulus) properties.



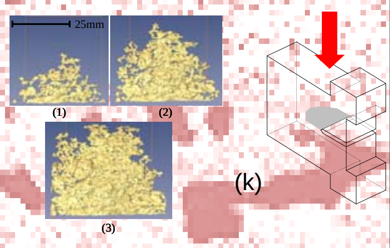
Crack Propagation and R-curve Behaviour

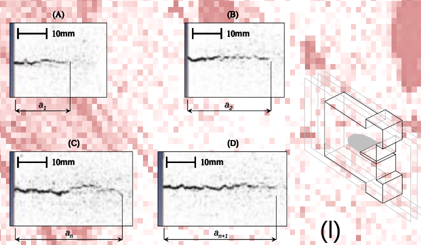
$$R = \frac{U}{b.\partial a} \quad J/m^2$$



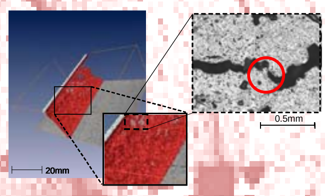
The crack resistance, R-, curve is a measure of the energy dissipated per unit area of crack as a crack propagates. The change in R with crack length indicates the stability of a crack. It is determined from a loading/unloading mechanical test (j). The crack front is assumed to be straight and its length given by that observed on the surface. R-curves could be used in safety cases for nuclear power plant.

XMT was used to give the crack geometry *in situ* for three load increments (k). The crack front is clearly not straight leading to potential significant errors in δa. The discontinuities in the crack surface indicate the presence of bridging ligaments.

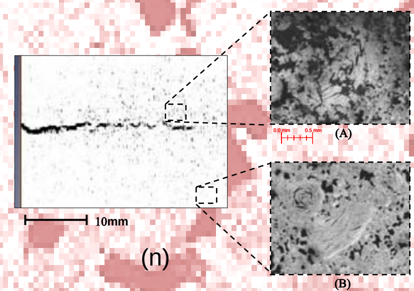




As XMT is non-destructive, the true crack length can be found within the specimen at each load cycle by virtual sectioning (l). This enables far more reliable data to be obtained. Note the haze of voids surrounding the crack.



(m)



(n)

XMT enables crack propagation mechanisms to be studied *in situ*. The figures show that both crack bridging (m) and microcracking (n) toughening mechanisms are in operation. A stable bridging zone behind and process zone ahead of the crack tip enable the form of the R-curve to be understood. The effect of graphite microstructure (filler size and shape, porosity) on properties can be found.

Conclusions

The study has shown that quantitative data can be determined non-destructively by XMT. These can be used to understand both physical and mechanical processes. XMT can be further developed to address issues in the behaviour of other inhomogeneous, anisotropic materials.

Acknowledgements

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