Insights into the fracture behavior of a fine nuclear graphite grade

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Outline

- Introduction, project overview and objectives
- Experimental set-up
- Digital Volume Correlation and strain analysis
- Plasticity extent during fracture propagation, size and temperature effects
- Future work and conclusion
The University of Manchester at Harwell

I13 X-Ray Imaging and Coherence
**Generation IV: Nuclear Energy Systems** Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics.
Diagram of a very-high-temperature reactor.

Introduction to Generation IV nuclear reactors, D. Buckthorpe 2017

Mechanical Behaviour: Quasi-brittle

Hodgkins A. et. al., Materials Science and Technology, 2006
Potential graphite grades for generation IV nuclear reactor

<table>
<thead>
<tr>
<th>Medium grade</th>
<th>Medium grade</th>
<th>Fine grade</th>
<th>Super fine grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size generally less than:</td>
<td>4 mm</td>
<td>100 µm</td>
<td>50 µm</td>
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</tbody>
</table>

Graphite as a core material for Generation IV nuclear reactors, B.J. Mardsen 2017


Mersen 2020

Average porosity: 9%
Diameter of porosity channels ≈ 20 µm
Standard benchmark experiment

Cady C. et al., AIP Conference Proceedings, 2018

4x4x12 mm$^3$  6x6x18 mm$^3$  8x8x24 mm$^3$
Standard benchmark experiment

Outputs revealed by image processing:
- Internal structure (porosity)
- Full displacement field
- Full strain field

Digital Volume Correlation (DVC)
Digital Volume Correlation

Elastic strain?  Plastic strain + strain fluctuations

Res. ≈ 100 µm

Compressive stress field

Normalized Occurrence
Plasticity visualization

Tensile strain value

Marrow T.J. et al., Carbon 96, 2016
Strain field =

- Continuum elastic stress field
- Localized plastic large strains?

→ Process zone
Strain field =

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- Localized plastic large strains?
  - Process zone
- PZ size: no size effect at 25°C
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Process zone
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Size effect exists
Strain field =
- Continuum elastic stress field
- Localized plastic large strains?

→ Process zone

- PZ size: no size effect at 25°C
- PZ size: no size effect at 200°C

Size effect exists
PZ size depends on the size of the different features in the internal structure:

Keyway root crack: less likely if PZ size is less than the keyway width.
Future work

- Energy dissipation within the PZ
Future work

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- Scaling with other geometry and with Gilsoncarbon
Future work

- Energy dissipation within the PZ
- Scaling with other geometry and with Gilsocarbon
- Experiment done over 25-200°C, what about VTH operating temperatures (> 1000°C)
Conclusion

- X-ray tomography is a suitable technique to analyze structural changes *in-situ* under load
- Plasticity monitoring
- Process zone size stable over 25-200°C and specimen size change
- Dimension criteria for catastrophic failure
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